AURA Applications

Division-Level Transportation and Selected Spares Issues

Robert Shishko, Milton Kamins

Rand

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 1984**	2. REPORT TYPE	3. DATES COVERED **00-00-1984 to 00-00-1984**
4. TITLE AND SUBTITLE **AURA Applications: Division-Level Transportation and Selected Spares Issues**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Rand Corporation,1776 Main Street, PO Box 2138,Santa Monica,CA,90407-2138**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**92**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The research described in this report was sponsored by the Office of the Assistant Secretary of Defense/Manpower, Installations and Logistics under Contract MDA903-83-C-0047.

Library of Congress Cataloging in Publication Data

Shishko, Robert.
AURA applications.

"R-3156-MIL."
"Prepared for the Office of the Assistant Secretary of Defense/Manpower, Installations, and Logistics."
1. AURA (Computer program) 2. United States. Army—Supplies and stores—Mathematical models. 3. United States. Army—Operational readiness—Mathematical models. 4. United States. Army—Combat sustainability—Mathematical models. I. Kamins, M. II. Rand Corporation. III. Title.
UC263.S457 1985 355.4'11'02854 84-24843
ISBN 0-8330-0612-6

The Rand Publication Series: The Report is the principal publication documenting and transmitting Rand's major research findings and final research results. The Rand Note reports other outputs of sponsored research for general distribution. Publications of The Rand Corporation do not necessarily reflect the opinions or policies of the sponsors of Rand research.

Published by The Rand Corporation

R-3156-MIL

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Division-Level Transportation and Selected Spares Issues

Robert Shishko, Milton Kamins

December 1984

Prepared for the
Office of the Assistant Secretary of Defense/
Manpower, Installations and Logistics

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PREFACE

This report was prepared as part of Rand's Defense Manpower Research Center Program, sponsored by the Office of the Assistant Secretary of Defense (Manpower, Installations, and Logistics)—OASD(MI&L). The study was conducted under Task Order 83-IV-2, Quantifying the Effect of Resource Levels on the Readiness of Ground Forces.

Readiness and sustainability issues are assuming an ever greater importance in defense planning and budgeting. Dealing with these issues requires the development of new methodologies for examining the relationship of resources to readiness and sustainability. This study is intended to contribute to a better understanding of that relationship and to the broader questions of readiness and sustainability confronting the Department of Defense. It is not intended as a cost-effectiveness study recommending specific policies.

The AURA (Army Unit Readiness/Sustainability Assessor) simulation can be used to assess the effect of resources on the mission-generation capabilities of combined arms units. AURA is an adaptation of the TSAR model developed by D. E. Emerson of The Rand Corporation under Project AIR FORCE sponsorship.

This report describes several applications of AURA. One is the measurement of the readiness and sustainability of a combined arms brigade supported by two artillery battalions, in which explicit consideration is given to the ability of the division and the brigade to move ammunition and petrol. A second application is an investigation of the potential of increased stocks of certain DX (Direct eXchange) items to increase sustainability; and a third is an examination of the effects of augmenting unit PLLs (Prescribed Load Lists) with certain mandatory spares. The simulations reported here use the most developed AURA data base for combined arms units; the same data base could be used for a variety of additional studies.

The report is one in a series of Rand documents on AURA and AURA-compatible models. The companion volumes include:

R-2769-MRAL, *Relating Resources to the Readiness and Sustainability of Combined Arms Units*, December 1981.

N-1460-AF, *TSARINA: User's Guide to a Computer Model for Damage Assessment of Complex Airbase Targets,* July 1980.

N-1987-MRAL, *AURA User's Manual: Vol. I, Program Features and Interactions,* June 1983.

N-1988-MRAL, *AURA User's Manual: Vol. II, Data Input and Sample Problem,* June 1983.

SUMMARY

AURA is a Monte Carlo event simulation model that permits decisionmakers to examine the implications of alternative resource levels on the output of combined arms units, and to assess a broad range of theater-wide resource allocation policies. By capturing the interdependencies among resources, AURA allows an integrated assessment of readiness and sustainability for ground combat forces.

Previously reported research using AURA examined the operations of a combined arms brigade of armored and mechanized infantry forces supported by a Forward Area Support Team (FAST) and a Division Support Command (DISCOM). That research demonstrated the usefulness of a tool like AURA for assessing the relationship between additional resources (e.g., manpower, spares, and replacement end items) and brigade output, but it did not take into account possible constraints on the delivery of POL, ammunition, and other consumables, or constraints posed by the maintenance requirements for other major weapon systems within the combined arms team. In this report, we describe new research applying AURA in an expanded context that explicitly takes into account POL and ammunition delivery capabilities within the division. We also report on two additional applications in which we sought to relate dollar resources directly to readiness and sustainability.

AURA with Transportation Constraints

The delivery of POL and ammunition from the division rear to the points of consumption in the task forces and artillery units is a complex but necessary combat service support function. To analyze the effect of resource limitations on these deliveries and their all-important subsequent effect on combat operations, we used a two-step procedure: first, using AURA, we determined the deliveries from the division support area forward to the brigade support area (to be described more fully later) and the subsequent movement of these stocks forward to the task forces and artillery batteries. We then ran another AURA simulation of the weapon systems constrained by the previously generated schedule of deliveries of POL and ammunition. This permitted us to determine the match between the delivery system capabilities and the needs of the weapon systems.

In the simulation of ammunition and POL movement, the division's transportation assets were used to move cargo from the division rear to the brigade. No corps transportation assets were assumed. Unit transportation assets picked up ammunition and POL in the brigade rear as well as in the division rear, and delivered them to the point of consumption at times permitted by the tempo of combat. A small attrition rate was applied to all transportation assets. The simulation was carried out for two levels of unit transportation assets, called FULLTRUCK and SHORTRUCK. In both of these, spares support was provided from Prescribed Load List (PLL) and Authorized Stockage List (ASL) stocks that might typically be found in representative units.

The simulated brigade consisted of three identical combined arms task forces, each with two tank companies and one mechanized infantry company, and was supported by two artillery battalions, a 155-mm Bn and an 8-in. Bn, both in direct support or direct support (reinforcing) roles. The pacing items were the M60A1, M113A1, M109A1, and M110. Two cases were run, with the distinguishing feature the spares support at the Division Support Command (DISCOM). In both cases, the brigade had a full TO&E complement of manpower and equipment, but in the first, known as the BASE CASE, the brigade had access to unconstrained spares from the DISCOM after exhausting the possibility of obtaining needed spares from its PLLs and forward ASL at the FAST. In the second case, known as SHORTPARTS, the DISCOM's spare stockage was more in line with actual practice. In essence, the two cases were characterized by unconstrained spares versus spares from a "constructed" division ASL and unit PLLs.

The brigade was simulated in two notional operations called SOCs (Specific Operational Capabilities). These were denoted the active defense SOC and the attack SOC. The results for the tank and artillery components of the brigade are presented in detail and support the following conclusions:

- The lack of spares significantly affects the sustainability of the brigade, especially after three days of combat operations.
- Ammunition Materiel Handling Equipment (MHE) at the DISCOM needs to be increased to handle peak uploading periods.
- With full division-level transportation assets and task force transportation assets modestly below TO&E levels, the simulated brigade can be supported with ammunition and POL in the active defense SOC. This only holds if the quantity of ammunition fired per tube, particularly for the artillery units,

does not exceed by much the amounts we have chosen for the simulation. These quantities were very close to the multi-day averages in Field Manual FM101–10–1, but may be significantly lower than other estimates. Our conclusion also assumes that for artillery units, delivered ammunition in excess of actual consumption is prepositioned early in the campaign for later use. Also, because of the stochastic nature of the problem, a unit could experience a spot shortage, should it find itself, for example, with a greater-than-expected number of artillery tubes ready to fire on a given mission and a less-than-expected number of trucks making ammunition deliveries that day.

- Ammunition and POL resupply for the brigade in the attack SOC is more tenuous, but still feasible. Again, an increase in the number of rounds fired by mission-capable tubes much beyond our assumed value could alter this result.
- Tank sustainability can be increased by having higher stocks of certain DX items, in particular, tank powerpacks. Each added day of sustainability costs more, ceteris paribus, than the last. Our rough estimate for powerpacks is that the first incremental day for all M60A1/A3 units deploying by M+30 costs $20 million, and the second, $50 million. (Of course, it might be possible that spending less than $50 million on another resource will also produce that second incremental day.)
- We could find no measurable effect of including MSL (Mandatory Stockage List) items and quantities in a well-supported demand-based PLL (leaving the ASL demand-based as well). When the MSL program is extended to the ASL level, then the overall effect can be tested with AURA.
- In all the stockage questions examined, cannibalization was an important source of spare parts in combat conditions. Cannibalization ought to be incorporated in MARC (Manpower Requirements Criteria, formerly MACRIT).

Pending Issues

Additional issues relating to this research are improving the quality of reliability and maintainability data, identifying the implicit and explicit assumptions behind current logistics planning factors, and relating budget dollars to readiness and sustainability. Developing a direct way of doing the last is difficult because readiness and sustainability are products not only of the requirements and budget processes, but also of the distribution and execution systems that follow.

ACKNOWLEDGMENTS

The authors wish to thank Lieutenant Colonel Dennis Gresdo (U.S. Army) and Dr. Jay Mandlebaum (OASD, MI&L), for the time and effort they contributed to the successful completion of this research. The authors also wish to thank Rand colleagues James Bigelow and Robert Paulson for their thoughtful suggestions for improving the exposition of this report.

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FIGURES

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GLOSSARY

AMSAA	Army Material Systems Analysis Activity
ARV	Armored Recovery Vehicle
ASF	Army Stock Fund
ASP	Ammunition Supply Point
ASL	Authorized Stockage List
ATP	Ammunition Transfer Point
AURA	Army Unit Readiness/Sustainability Assessor
BRL	Ballistics Research Laboratory
CBR	Chemical, Biological, Radiological
CONUS	Continental U.S.
COSAGE	Combat Sample Generator
COSCOM	Corps Support Command
CSA	Corps Support Area
DA	Department of the Army
DARCOM	Development and Readiness Command
DISCOM	Division Support Command
DS	Direct Support (Level of Maintenance)
DS/R	Direct Support, Reinforcing (Artillery)
DX	Direct Exchange (Item Class)
FAST	Forward Area Support Team
FDP	Fuel Distribution Point
FM	Field Manual
FORSCOM	Forces Command
GS	General Support (Level of Maintenance)
HET	Heavy Equipment Transporter
LPF	Logistics Planning Factor
MARC	Manpower Requirements Criteria (Formerly MACRIT)
METT	Mission, Enemy, Terrain, and Troops Available
MHE	Materiel Handling Equipment
MSL	Mandatory Stockage List
MSR	Main Supply Route
OPLAN	Operations Plan
OSD	Office of the Secretary of Defense
PLL	Prescribed Load List (Supply)
POL	Petroleum, Oil and Lubricants
POM	Program Objective Memorandum
PPBS	Planning, Programming and Budgeting System
PSP	Pre-Stock Points
R/S	Readiness/Sustainability

S&T	Supply and Transportation
SOC	Specific Operational Capability
SP	Self-Propelled
SPARC	Sustainability Prediction for Army Spare Components Requirements for Combat
TACOM	Tank-Automotive Command
TF	Task Force
TO&E	Table of Organization and Equipment
TR	Theater Reserve
TSAR	Theater Simulation of Airbase Resources
USAREUR	U.S. Army, Europe
WARRAMP	Wartime Requirements for Ammunition, Materiel, and Personnel

I. INTRODUCTION

The Department of the Army (DA) has over the past few years attempted to identify and correct those resource deficiencies and problem areas that led to public concern in the late 1970s over the readiness and sustainability of U.S. ground forces. Although management initiatives and investments in manpower, equipment, spares, and ammunition have resulted in substantial improvements, there are few analytic tools to help DoD decisionmakers project how various resource allocations will affect readiness and sustainability. AURA (Army Unit Readiness/Sustainability Assessor) is a tool that can fulfill part of this need.

AURA is a Monte Carlo event simulation model that permits decisionmakers to examine the implications of alternative resource levels on the output of combined arms units, and to assess a broad range of theater-wide resource allocation policies. By capturing the interdependencies among resources, AURA allows an integrated assessment of readiness and sustainability for ground combat forces. The AURA simulation itself is a derivative version of a Rand-developed model, called TSAR, designed to answer similar questions for the U.S. Air Force. For a more detailed description of AURA, see Appendix A.

Previous research using AURA examined the operations of a combined arms brigade of armored and mechanized infantry forces supported by a Forward Area Support Team (FAST) and a Division Support Command (DISCOM). That research demonstrated the usefulness of a tool like AURA for assessing the relationship between additional resources (e.g., manpower, spares, and replacement end items) and brigade output, but it did not take into account possible constraints on the delivery of POL, ammunition, and other consumables, or constraints posed by the maintenance requirements for other major weapon systems within the combined arms team. In this report, we reveal new research applying AURA in an expanded context that explicitly takes into account POL and ammunition delivery capabilities within the division. We also report on two additional applications in which we sought to relate dollar resources directly to readiness and sustainability.

AN APPROACH TO READINESS AND SUSTAINABILITY MEASUREMENT

It is useful first, however, to state the approach and philosophy that this work has taken, both as a way of enhancing the reader's understanding of what it takes to measure readiness and sustainability, and as a way of contrasting this work with that of others. We believe there is more to the measurement of combat readiness and sustainability than just the static availability of combat equipment and the personnel to run them. Those measures neglect such important considerations as the quantity and location of support resources, the pattern of theater-wide interactions among resources, and most important, the dynamics of wartime operations.

Our concept of readiness and sustainability reflects the principles found in the current DoD definitions. Readiness refers to the ability of forces to deliver the output for which they were designed into the initial period of combat. Sustainability refers to the ability to continue delivering that output over a longer period of time. Readiness and sustainability are closely related in these definitions because the resources that produce readiness—personnel, equipment, and consumables—overlap with those that produce sustainability. At the same time, readiness and sustainability require unique resources as well. In keeping with the above definitions, our concept of readiness and sustainability refers to the projected capability of a force to meet the combat requirements of a set of wartime scenarios—that is, a readiness and sustainability measure must be output-related, and that output must be tied to specific assumptions about how, where, when, under what circumstances, and with what resources each unit must fight.

MAKING THE CONCEPT WORK

To make this concept work, we first defined a collection of "notional operations" for combined arms units—for example, a maneuver task force operating in the VII Corps area. We called each of these notional operations a Specific Operational Capability (SOC) because each represents something a unit must be able to execute in wartime (and what it practices in peacetime). Each SOC specifies a series of maneuvers or missions that must occur at certain times, and the consumption rates for certain classes of supply that are expected to occur. Each SOC may also specify particular environmental factors in which a unit may be employed, e.g., a CBR-contaminated battlefield.

Next, we had to identify the resources available to each unit within the context of the Army's multi-echeloned support system. This was

necessary because a unit is not expected to operate for long without logistic support from its parent brigade, division, and corps. Last, we used the AURA simulation to measure the ability of each unit within a combined arms brigade to carry out a variety of SOCs with its available resources over an extended period of time, in this case, 15 days. It is important to note that AURA could have handled a corps-sized simulation over a much longer period and with a wider variety of unit types than we used in our research. Our choice of a brigade-sized force was to gain some research experience at this level before modeling larger organizations.

In Section II, we expand on previous AURA work by introducing two artillery battalions in direct support of the maneuver task forces, and by including the transportation of POL and ammunition from the division rear to the points of consumption in the task forces and artillery batteries. In Section III, we apply AURA to selected spares issues that are of current interest in the programming and budgeting process. Section IV presents some conclusions and observations.

II. INCORPORATING TRANSPORTATION CONSTRAINTS INTO AURA

The delivery of POL and ammunition from the division rear to the points of consumption in the task forces and artillery units is a complex but necessary combat service support function. To analyze the effect of resource limitations on these deliveries and their all-important subsequent effect on combat operations, we used a two-step procedure: First, using AURA, we determined the deliveries from the division support area forward to the brigade support area (to be described more fully later) and the subsequent movement of these stocks forward to the task forces and artillery batteries. We then ran another AURA simulation of the weapon systems constrained by the previously generated schedule of deliveries of POL and ammunition. This permitted us to determine the match between the delivery system capabilities and the needs of the weapon systems. The two-step procedure had two advantages. Without loss of detail, it proved less expensive than a combined simulation, and it yielded an AURA data base that could be used in isolation to further study division- and brigade-level transportation issues.

AMMUNITION AND FUEL RESUPPLY

The movement of ammunition is depicted schematically in Fig. 1. Corps trucks generally move ammunition forward from Pre-Stock Points (PSPs) and Corps Storage Areas (CSAs) to Ammunition Supply Points (ASPs) located in the division support area, or directly to Ammunition Transfer Points (ATPs) in the brigade rear. Division trucks may be used to fill the ASPs or move ASP stocks forward to the ATPs. Organic assets of each task force or artillery battalion may either pick up ammunition at an ATP, or if all demands can not be satisfied there, at a division ASP. Generally, ammunition is unpalletized at the ATP when it is loaded onto task force or battalion trucks in various mixes depending on the unit's requirements. Temporary storage of ammunition in this process may be on the ground, or if possible, on S&P (stake and platform) or other trailers.

Fuel movement and storage are similar. As a general rule, the Corps Support Command (COSCOM) delivers bulk fuel to division fuel distribution points. Division fuel tanker-trucks deliver this bulk fuel

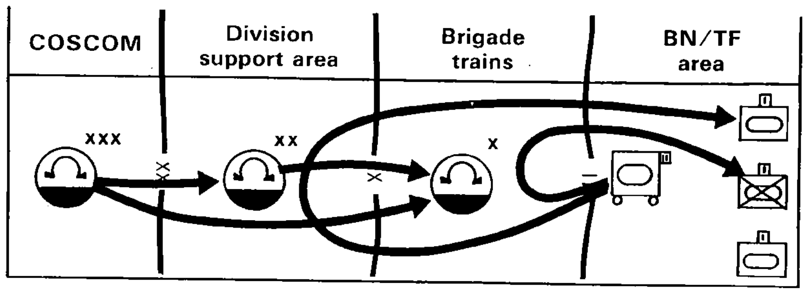

Fig. 1—Ammunition supply

forward to fuel distribution points in the brigade rear, or if necessary directly to the task forces and artillery battalions. Fuel tankers organic to the task forces and artillery battalions move fuel from the brigade fuel distribution points to the points of consumption in the task forces and battalions. Although it is considered desirable to keep the bulk fuels as mobile as possible, i.e., on tankers, it is possible to store POL in the division's fuel storage systems, which might include six 10,000-gal collapsible fabric tank assemblies, 27 500-gal collapsible fabric drums, plus a large number of 55-gal drums.

The division and its organic battalions have a large number of trucks, tractors, trailers, tankers, and semi-trailers of various capacities, but not all of them are available to move ammunition and POL. Some must be dedicated to moving communication gear, providing food service, and holding maintenance equipment, tools, and spare parts, as well as medical supplies and temporary shelters. Table 1 shows division transportation assets by unit type, excluding small vehicles, and assets available to move ammunition and POL. The distinction can generally be made by reference to detailed TO&E listings for each platoon and section. The numbers in Table 1 were obtained in this way using the H-series TO&Es for an armored division.

In our AURA simulation of transportation capabilities, we ran two levels of assets—one called FULLTRUCK, in which units had their full TO&E complement of assets, and a second called SHORTTRUCK,

in which units had the smaller numbers of assets shown in italics.[1] SHORTRUCK represented a modest overall reduction in one-time organic lift capacity, about 25 percent for cargo and 33 percent for POL at each maneuver task force, and about 22 percent for cargo at each artillery battalion. Note that in SHORTRUCK no reductions were made in the division's S&T (Supply and Transportation) Battalion.

The AURA simulation organized and assigned these division and unit resources, including those at support locations, to meet our specified mission demands. It kept track of each vehicle, each resource available, and each resource consumed in the process of conducting these missions as well as those for maintaining, fueling, loading, and unloading the vehicles. Various management decision rules in AURA permit units to respond intelligently to the operations, supply, and maintenance events that are stochastically generated.[2] To assess the

Table 1

TOTAL (AND AVAILABLE) TRANSPORTATION ASSETS

	Trucks				Tractors	Semi-trailers and Trailers			Tracked Carriers
Unit	2½t	5t	8t	2500-gal	5t	1½t	12t	5000-gal	6t
Armor Bn	21 (6) *(5)*	6 (6) *(4)*	5 (5) *(4)*	4 (4) *(3)*	—	14 (12)	—	—	—
Mech Inf Bn	19 (6) *(5)*	6 (6) *(4)*	5 (5) *(4)*	2 (2) *(1)*	—	19 (12)	—	—	—
155-mm Bn	19 (9) *(9)*	3 (0)	18 (18) *(13)*	2 (2) *(2)*	—	44 (36)	—	—	18 (18)
8-in. Bn	19 (9) *(9)*	4 (2) *(2)*	18 (18) *(13)*	—	—	42 (30)	—	—	18 (18)
S&T Bn	73 (60)	6 (6)	—	—	41 (40)	73 (65)	20 (20)	30 (30)	—
Maint Bn	92 (6)	3 (0)			56[a](6)	75 (6)	17[b](0)	—	—

[a]Plus 6 HETs (Heavy Equipment Transporters).
[b]Plus 31 low-bed container semi-trailers.

[1]If no figure appears in italics, we retained the FULLTRUCK assets.

[2]To generate unscheduled maintenance events, for example, we used the task frequency and task time data in the Contingency Maintenance Allocation Charts (CMACs) for all vehicles. Only those tasks that were considered mission-essential were modeled in AURA, i.e., included in AURA's maintenance data base.

output of combat, combat support, and combat service support units over a sustained period, which is the objective of this research, a number of assumptions and policies need to be considered. A partial list of such assumptions and policies is shown as Table 2. These assumptions and policies are important precisely because they affect readiness and sustainability. The richness of the AURA simulation is apparent because these are explicitly considered.

Table 2

ASSUMPTIONS AND POLICIES IN AURA

- Maintenance
  - Essentiality/criticality/incompatibility
  - Job priorities/deferrals
  - Cannibalization policies
  - Management of "long" jobs
  - Specialized equipment
- Supply
  - Stockage and prepositioning policies
  - Major end item replacement policies
  - Delivery delays
- Manpower
  - Task qualification/cross training
  - Sleep/rest requirements
  - Crew and maintenance personnel losses
- Operations
  - Planning window
  - Reconstitution following enemy attack
  - Recovery policies

AURA RESULTS FOR AMMUNITION RESUPPLY

We chose to simulate the following conditions: The division's medium truck company of the S&T Bn would move stocks forward from a single ASP in the division rear to three ATPs, one for each assigned brigade. The ASP would be stocked by the COSCOM in sufficient quantities so that there would be no division-level (ASP) shortages. The Materiel Handling Equipment (MHE) at the DISCOM was twice what the TO&E called for—that is, we doubled the number

of forklifts from the TO&E levels.[3] The task forces and artillery battalions would send the bulk of their trucks to an ATP, but would allocate a portion to long-haul trips to the ASP. This ensured that the appropriate mix of munitions could always be obtained.

Division trucks attempted four round trips (missions of about 80 km each) to an ATP each day—three daytime departures and one nighttime. During each departure window, convoys were formed (in accordance with doctrine) so that groups of one to six trucks were spaced out along main supply routes (MSRs). Unit trucks attempted three resupplies of ammunition (each between 38 and 53 km) each day in between the three daily operations that make up the active defense SOC. Unit trucks used for long-haul resupply (about 130 km each round trip) attempted two such missions a day. A small attrition rate (one percent) was applied to each mission between the ASP and ATPs, whereas a larger rate (three percent) was applied to missions operating forward of the ATPs. We also assumed there was no significant damage to the transportation network (roads, bridges, etc.) that would drastically alter travel times; in AURA all mission lengths, however, have a stochastic component.

Organizational maintenance for the medium truck company was provided by its own maintenance platoon and direct support (DS) maintenance by the division's maintenance battalion attached to the DISCOM. Trucks organic to units were maintained by the organizational maintenance personnel in them, or if DS work was required, by the FAST. Trucks were supported by spares from their own unit's Prescribed Load List (PLL) and the division's Authorized Stockage List (ASL). Following our usual procedure, we constructed these PLLs and ASL from a composite of several real units' stockage. The procedure guarantees generally robust spares support because we include a part if it appears on *any* of the real stock lists in our possession, and we include it at the maximum depth of those lists.

Deliveries to the ATP

Figure 2 shows the daily movement capacity in short tons of the division's S&T Bn from the ASP to the three ATPs estimated by AURA under the above assumptions for the FULLTRUCK case. These estimates represent average outcomes over 15 trials. At this number of trials, standard errors in AURA are typically small. We

[3]This was necessary because when the original level was run, the DISCOM could not upload the S&T Bn's trucks fast enough and the entire operation could not move anywhere near the tonnages required.

compared this capacity with the ammunition consumption forecasts in FM101-10-1.[4] That Field Manual states a demand for ammunition of an armored division on defense (first day and subsequent days) shown as the straight line in the figure. The apparent match may be illusory as there is no guarantee that the correct mix of munitions is being delivered, and as there seem to be several Army projections of ammunition consumption that are distinctly different, e.g., Supply Bulletin 38-26 and the Logistics Planning Factors Manual. In any case, the deficit in Fig. 2 over the first few days is supposed to be covered by each unit's basic load. The basic load is computed as the amount of ammunition needed before resupply is established.

Total Deliveries to Points of Consumption

Deliveries to the ATPs and the subsequent evacuations from them may not be sufficient to support each unit's operations. Consequently some units may need to supplement what they get from an ATP with ammunition directly from the division or corps ASPs. Total deliveries to units will then be different from those shown in Fig. 2. Figure 3 shows those total deliveries in short tons to each task force and artillery battalion as estimated by AURA, again using the assumption described above for the FULLTRUCK case. These estimates represent average outcomes over 15 trials for the artillery units and 45 trials for the maneuver unit. We observed, however, individual task forces and

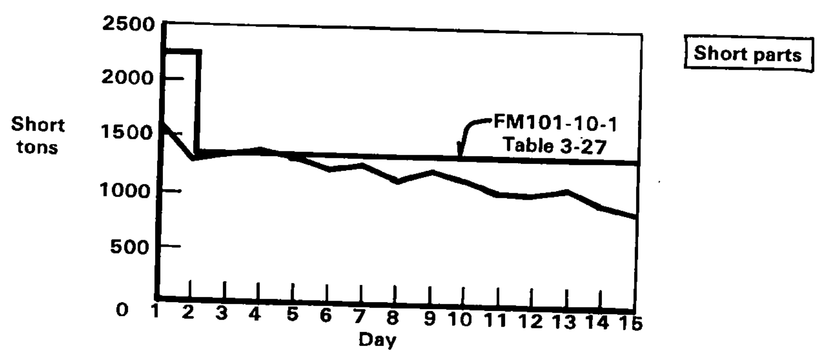

Fig. 2—Division ammunition resupply capability using organic S&T assets

[4]Headquarters, Department of the Army, *Staff Officers' Field Manual: Organizational, Technical, and Logistical Data,* July 1976, Table 3-27.

artillery battalions in particular trials (seeds) that fared substantially worse (and better) than the average.

The oscillations in deliveries of artillery ammunition, especially noticeable for the 155-mm battalion, are due to the queueing of trucks at the ATP as they wait for deliveries from the ASP. In other words, the cyclical variation is due to the mismatch of deliveries to the ATP, and hence stocks there, with the ability of the artillery battalions to deliver munitions from the ATP to their gun tubes. Indication of this is seen in the buildup of ammunition stocks at the (typical) ATP, which is shown in Figs. 4a and 4b below. The figures show the (average) actual stock levels at midnight each day from the AURA simulation. The short tons scale is supplemented by a days-of-supply scale, which is calculated here by assuming that each gun tube fires the average number of rounds specified in the active defense SOC.[5] Figure 4a

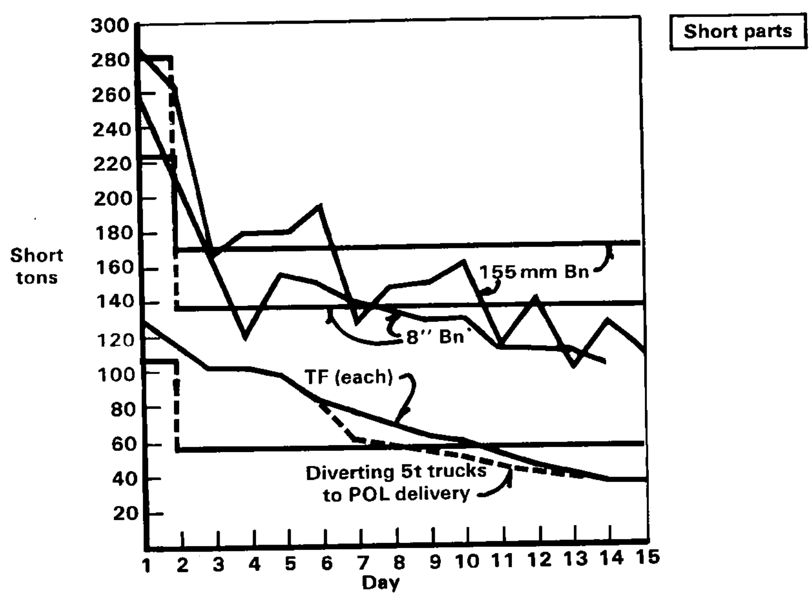

Fig. 3— Ammunition deliveries to consumption points (FULLTRUCK)

[5]Daily firing rates for this calculation were: 180 rounds for the 155-mm self-propelled (SP) howitzer (M109A1), 125 rounds for the 8-in. SP howitzer (M110), and 63 rounds for the tank (M60A1). These rates in FM101-10-1 (Table 3-27) are 231, 143, and 78,

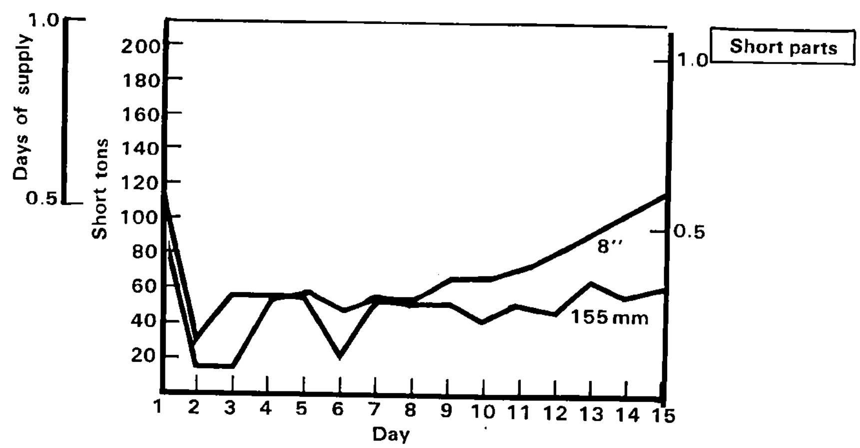

Fig. 4a—ATP stocks of artillery ammunition (FULLTRUCK)

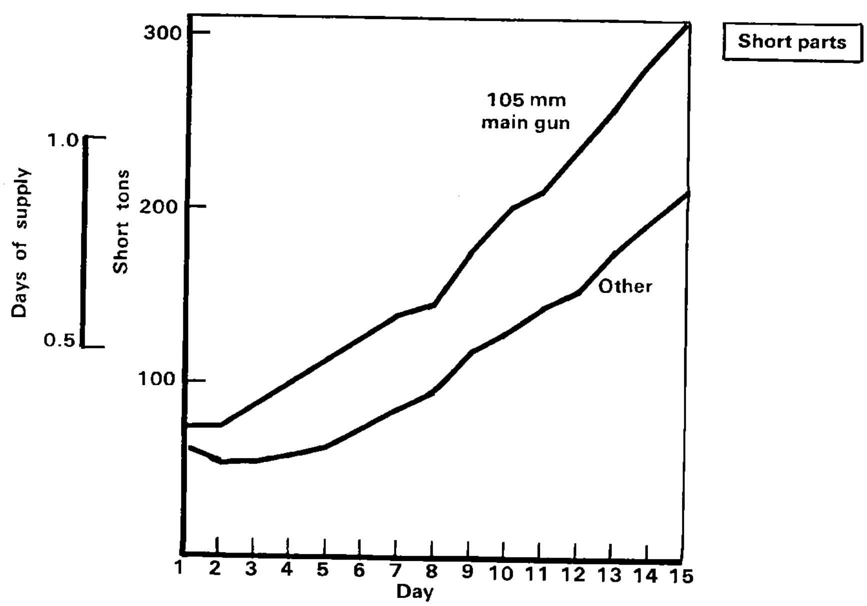

Fig. 4b—ATP stocks of task force ammunition (FULLTRUCK)

shows that the buildup rate for artillery ammunition at the ATP is slow at best, even taking into account the fact that attrition and mechanical failures stretch a given tonnage of ammunition into more days of supply.[6] On several days there are less than 20 short tons of 8-in. munitions (about 150 rounds) and less than 25 short tons of 155-mm munitions (about 365 rounds). The situation is better for tank main gun and other ammunition, which includes missiles, mortar rounds, and machine gun and small arms ammunition. Even in these categories, less than 200 short tons is available at the ATP for all three task forces.

We compared the total delivery capability with estimated ammunition consumption based on the active defense SOC consumption rates (see App. B) for the simulated pacing items and FM101–10–1 rates for all other weapons.[7] Estimated consumption is shown as the straight lines in Fig. 3 above. Although the estimated delivery and consumption rates are similar, the "requirements" calculation does not take into account either ammunition losses to enemy action on the one hand, or attrition of weapon systems, or maintenance and supply delays on the other. Consequently, the apparent shortfalls may be either more serious or less serious than they appear when those factors are considered. These "requirements" are also quite different from the Army's Logistics Planning Factors (LPFs), and there appears to be no particular pattern of biases. For example, the LPFs suggest an ammunition consumption rate for the maneuver task forces that is considerably lower than that shown in Fig. 3, and for the 155-mm Bn, one that is considerably higher; only for the 8-in. Bn do they more or less agree.

Total Deliveries with SHORTRUCK

When we used the transportation assets of the SHORTRUCK case, overall deliveries dropped about 20 percent, but the most striking effect was observed for the delivery of artillery ammunition. The oscillations in deliveries ceased, apparently because there was little queueing by unit trucks at the ATP (see Fig. 5). Now, when a unit truck arrives at

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respectively, for the first day in defense of a position, and 140, 87, and 47 for succeeding days.

[6]A slow buildup is desirable if the ATP may be overrun by enemy forces.

[7]The details of this calculation are shown in App. C. A comparison of the SOC consumption rates and those in FM101–10–1 is given in footnote 5 above.

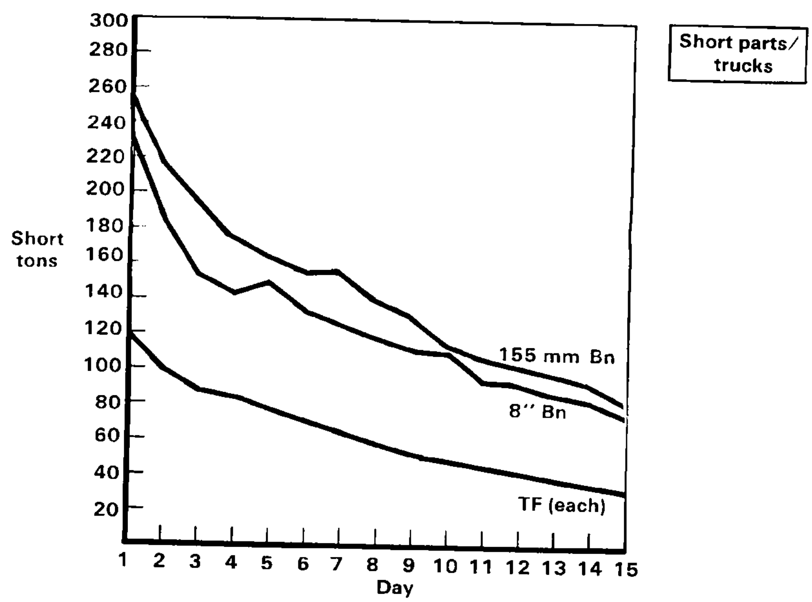

Fig. 5—Ammunition deliveries to consumption points (SHORTRUCK)

the ATP, there is ammunition waiting for it rather than the other way around. This is because in the SHORTRUCK case the deliveries to the ATP keep up with the ability of the units to empty it.[8] We see also that the curve of SHORTRUCK deliveries to the 155-mm Bn rests more or less along the bottom of the curve for the FULLTRUCK case.

The behavior of ATP artillery stocks is instructive. Figure 6 shows the short tons of supply of 155-mm and 8-in. munitions on hand at the ATP at midnight of each day in the SHORTRUCK case. The level is never as low as in the FULLTRUCK case, and the buildup of ATP stocks is considerably faster.

[8]It is impractical to divert division transportation resources, which are configured to carry large palletized loads on main roads, not to deliver smaller packages cross-country to end users.

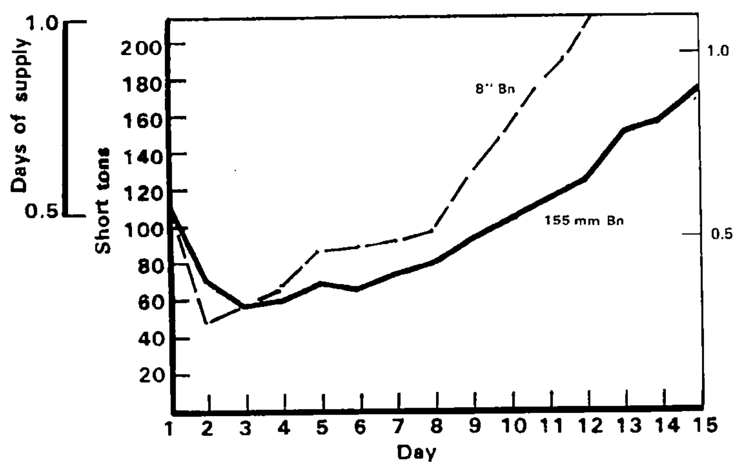

Fig. 6—ATP stocks of artillery ammunition (SHORTRUCK)

AURA RESULTS FOR FUEL RESUPPLY

The division's 5000-gal fuelers are used to move POL from the division rear to the brigade rears. In the AURA simulation of this, four round trips of approximately 80 km each, including one nighttime round trip, are attempted. Unit fuel trucks and 2500-gal fuel tankers attempt to refuel their unit's combat vehicles twice a day from supplies at the brigade fuel distribution point.

The division's estimated ability to deliver POL forward using the 5000-gal fuelers of the S&T Bn is shown in Fig. 7. Unfortunately, no reliable estimate of the overall requirement could be inferred from either FM101-10-1 or the LPFs. At the task force and battalion level, however, we were able to compare the "requirements" for POL and the deliveries in support of the active defense SOC estimated by AURA. The estimated deliveries are shown in Figs. 8a and 8b for the typical task force and the two artillery battalions. Each task force in the brigade had three 2500-gal fuelers, with one at the FAST for refueling repaired vehicles and for replacement purposes. The 155-mm Bn had two 2500-gal fuelers, whereas the 8-in. Bn used its 5-ton trucks with fuel bladders for POL resupply. Because of the small number of fuelers at each task force, the loss of, say, one to enemy action and one

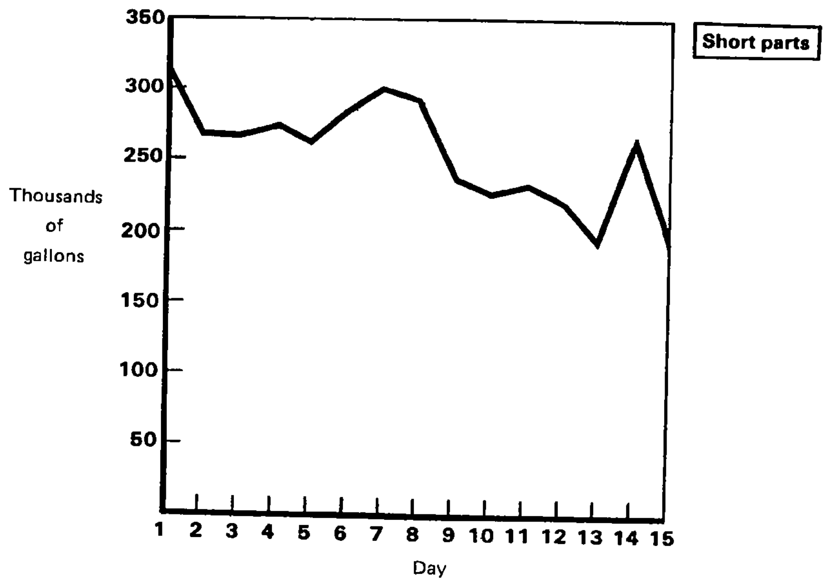

Fig. 7—Divison POL resupply capability using organic assets

to maintenance/supply delay could seriously impair a unit's ability to move. The rapid decline in POL deliveries to the task forces using their 2500-gal fuelers (Fig. 8a) forced a diversion of their 5-ton trucks from ammunition delivery to POL delivery, as shown previously in Fig. 3. This diversion was sufficient to provide the needed POL, but it reduced the flow of ammunition starting on Day 7 of the simulation; the reduced flow of ammunition, however, did not at that stage affect the task force's output. (See note to Fig. 10.)

The straight lines in Figs. 8a and 8b represent an estimate of "requirements" based on the active defense SOC fuel consumption rates for pacing items and FM101-10-1 fuel consumption rates for all other items. As before, no equipment losses were assumed. The details of this calculation are shown in App. D. Under the unrealistic assumption that no weapon system losses occur, the deliveries exceed the requirements early in the simulation, but shortfalls occur later.

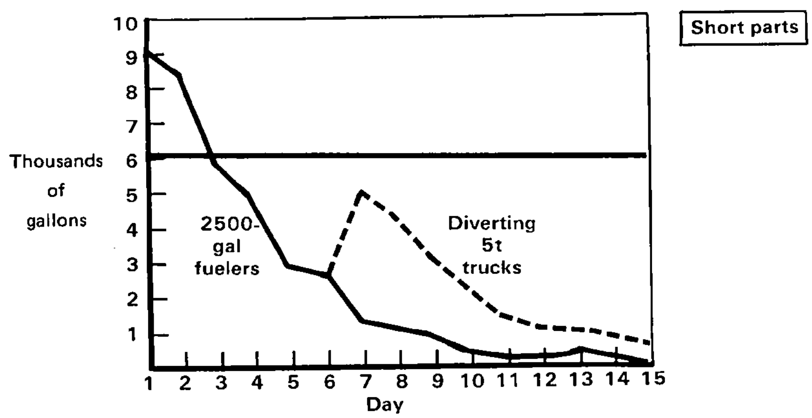

Fig. 8a—POL deliveries (diesel fuel) to task force consumption points (FULLTRUCK)

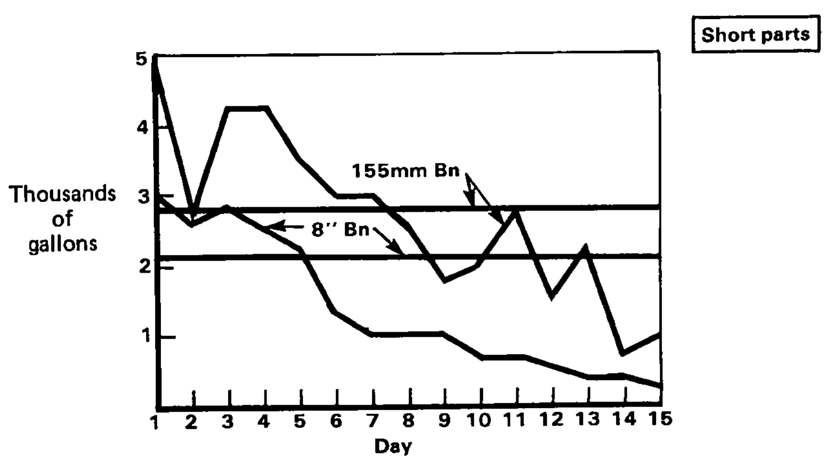

Fig. 8b—POL deliveries (diesel fuel) to artillery consumption points (FULLTRUCK)

AURA BRIGADE RESULTS FOR THE ACTIVE DEFENSE SOC

The active defense SOC is described in detail in App. B. In essence, this SOC is a series of three short battles (operations or missions) with a relatively short recovery period in between each. The three battles take place over a 24-hour period and reflect the need by the brigade to operate both day and night. To determine whether the POL and ammunition deliveries can support the task forces and artillery battalions in the active defense SOC, we simulated the combined arms brigade under that SOC with the expected deliveries of POL and ammunition from the earlier simulation. At this point, tonnages were converted to rounds of 105-mm, 155-mm, and 8-in. munitions, boxes of .50 cal and .30 cal, and rounds of "other" munitions (representing missiles and mortar shells).

The brigade was divided into three identical combined-arms task forces, each with two tank companies and one mechanized infantry company. Two cases were run, the distinguishing feature being the spares support at the DISCOM. In both cases, the brigade had a full TO&E complement of manpower and equipment, but in the first, known as the BASE CASE, the brigade had access to unconstrained spares from the DISCOM after exhausting the possibility of obtaining needed spares from its PLLs and forward ASL at the FAST. In the second case, known as SHORTPARTS, the DISCOM's spares stockage was more in line with actual practice. In essence, the two cases were characterized by unconstrained spares versus spares from a "constructed" division ASL and unit PLLs. The method of constructing the division ASL and unit PLLs was the same as that described for the simulation of POL and ammunition deliveries.[9] Spare parts support was, however, more important here because combat vehicles tend to be less reliable than trucks, and downtime tends to affect output more.

The overall attrition rate for each weapon system is an important parameter in the simulation because an enemy hit sets off a sequence of attrition, battle damage, and recovery events. We used the overall attrition rates shown in Table 3. The full sequence of subsequent events is spelled out for each weapon system in App. E.

[9]For the M60A1, 199 parts or kits were identified in the CMAC; of these, 134 (67 percent) appear in our constructed spares lists, but only 118 (59 percent) were actually available, i.e., not temporarily out-of-stock. For the M113A1, 164 parts or kits were CMAC-identified, 102 (62 percent) were listed, and 79 (48 percent) were available; for the M109A1, 124 parts or kits were CMAC-identified, 57 (46 percent) were listed, and 54 (44 percent) were available; for the M110, 102 parts or kits were CMAC-identified, 46 (45 percent) were listed, and 43 (42 percent) were available.

Table 3

ATTRITION ASSUMPTIONS FOR ACTIVE DEFENSE SOC

	Assumed Attrition Probability				
Vehicle	(1) Hit on Mission	(2) Complete Loss Given a Hit	(3) Complete Loss on a Mission[a]	(4) Hit in a Day[b]	(5) Complete Loss in a Day[c]
M60A1	.034	.829	.028	.098	.082
M113A1	.0175	.3425	.006	.052	.018
M109A1					
Fire support	.0133	.225	.003	.065	.015
Counter-battery	.0089	.225	.002		
M110					
Fire support	.0133	.225	.003	.056	.013
Counter-battery	.0089	.225	.002		

[a]Column (1) times Column (2).
[b]Computed as $1 - (1 - x)^n$, where x = Column (1) and n is number of missions per day.
[c]Computed as $1 - (1 - x)^n$, where x = Column (3) and n is number of missions per day

In the series of figures below, we illustrate the output of two weapon systems, the M60A1 tank and 8-in. SP howitzer, over 15 days of simulated operations.[10] We assumed that all weapon systems were combat ready at the beginning of the simulation, all were configured for the first mission each is to perform, and all were uploaded with fuel and ammunition at the start.

Tank Output Without End Item Replacement

Figure 9 shows the tank output (platoons generated at the time called for in the SOC) per mission as a function of the number of days in combat. The maximum is 18 because there are two battalions of three companies, each with three platoons. If the brigade commander

[10]Each SOC is repeated daily. Although we are aware this may be unrealistic, our purpose here is illustrative. A further discussion of this point and when the battle might realistically terminate is found in R. Shishko and R. M. Paulson, *Relating Resources to the Readiness and Sustainability of Combined Arms Units*, The Rand Corporation, R-2769-MRAL, December 1981.

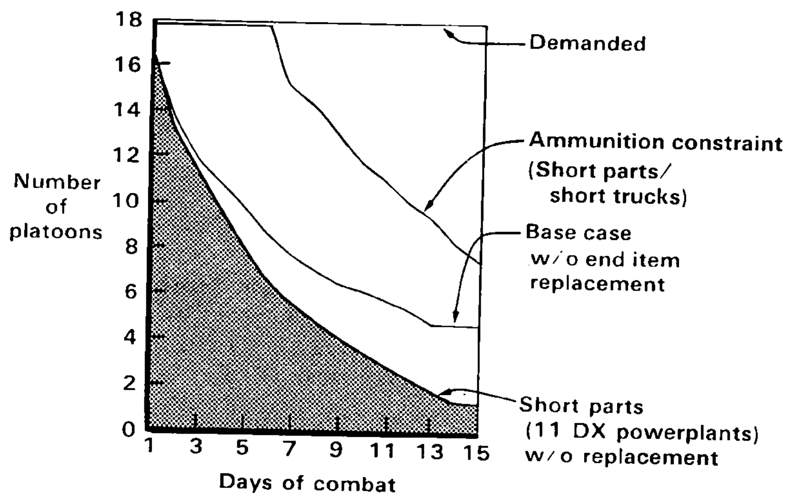

Fig. 9—Tank missions demanded/accomplished (active defense SOC)

would like to have all 18 platoons for each mission, then the box would represent the total demand for tank output. A lesser demand is of course possible depending on the METT (Mission, Enemy, Terrain, and Troops available). The curve labeled "Base case" represents the daily tank output for a brigade with a full TO&E. The area in the upper portion of the box to that curve represents output lost to four factors, each of which can be distinguished in the AURA output: (1) enemy-imposed attrition that the brigade cannot replace, (2) delay in the delivery of parts from the DISCOM,[11] (3) the limited manpower and recovery assets inherent in the TO&E, and (4) the inherent length of the bigger maintenance jobs (including battle damage repair) that precludes those sidelined tanks from being able to fight the next battle.

The curve labeled "Short parts" is the daily tank output for the identical brigade except that spares support is based on the constructed PLLs and ASL. The area in between the two curves is the additional output lost when spare parts at the DISCOM are drawn from more

[11]Although spares in the BASE CASE are unconstrained at the DISCOM, we have imposed in AURA a 24-hour delay in the receipt of a part from the DISCOM. This will potentially result in the loss of several missions by that sidelined tank.

typical stockage levels. This difference in output becomes significant after three days of active defense missions.

For both of these curves, ammunition and POL were delivered according to the earlier AURA transportation simulation (Figs. 3, 8a with diversion, and 8b), but it is possible to compute how much tank activity could have been supported. For ammunition, the tank activity that could have been supported in the SHORTRUCK case described previously is shown by the curve labeled "Ammunition constraint." At no time during the simulation does the delivery capability (resupply rate) fall below that required by mission capable tanks—either in the BASE CASE or the SHORTPARTS case—even with less than full truck strength. A fortiori, the same is true for the FULLTRUCK case. Similarly, POL resupply rates, not shown in the figure, were sufficient to support mission capable tanks. Ammunition and POL resupply were not binding constraints for the M60A1 in the active defense SOC simulated here. In part this was due to high attrition imposed on the tanks relative to the trucks, the fact that the ATP was able to operate continually, and that supply lines were not growing longer over time.

Tank Output with End Item Replacement

In an excursion of the above simulation, we replaced tank losses with maintenance float vehicles and TR-1 stocks. These replacement end items were allotted to the brigade on a fair share basis—that is, each brigade in the division received the same number. The schedule for such replacements was fixed, and is shown below as Table 4; alternatively, we could have used another replacement policy such as replacing permanently damaged tanks with a delay of, say, two days, had we selected this option within AURA.

Table 4

END ITEM REPLACEMENT SCHEDULE

Day Delivered	Number of Tanks per Task Force
4	3
7	2
9	2
11	2
13	2

NOTE: Brigade total is 33 tanks.

The results are shown in Fig. 10 for the BASE CASE and the SHORTPARTS case. In both cases, the output of the brigade is higher, as expected; in fact a comparison of Figs. 9 and 10 reveals that the "Short parts" brigade with end item replacement of Table 4 does about as well as the "Base case" brigade without replacement. The upper area within the box still includes some enemy-imposed attrition that the brigade cannot replace. Specifically, Table 4 indicates that 33 tanks are sent forward as replacements, yet expected losses amount to about 51 tanks. The curve labeled "Short parts/short trucks" again represents the level of tank activity that could be supported by the ammunition resupply system; POL deliveries (not shown) were also sufficient to support mission capable tanks if diversions are made (starting on Day 7) of 5-ton trucks from ammunition deliveries to fuel deliveries, as shown in Fig. 8a.

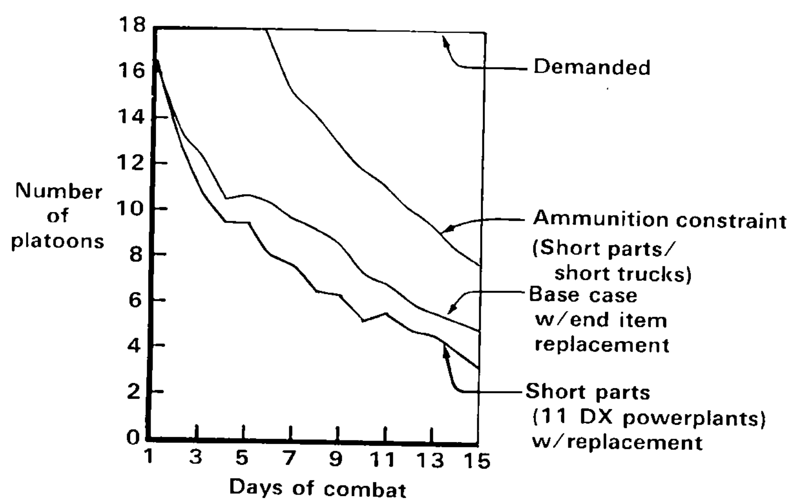

Fig. 10—Tank missions demanded/accomplished with replacement (active defense SOC)

Fire Support Output

For the simulation of the two artillery battalions, we permitted the deferral of certain maintenance tasks that did not affect the ability of a tube to fire. In particular, those automotive repairs that would not

prevent the vehicle from being towed from one firing point to another were deferred until the overnight recovery period. This had the effect of raising the number of "ready" tubes (i.e., output) on most fire support missions. The fire support output of the 8-in. Bn is depicted in Fig. 11, both for the BASE CASE and the SHORTPARTS case. The BASE CASE shows a roughly steady output around eight tubes per fire support mission.[12] The detailed diagnostics in AURA permit an examination of why this occurs. Such an examination reveals that early in the simulated period of operations, about one artillery piece has been lost to enemy action, one to two are awaiting or undergoing organizational maintenance at the time they are needed in the SOC, and one to two more are at the FAST awaiting or undergoing DS maintenance. Later in the simulated period of operations, perhaps two artillery pieces have been lost to enemy action, one is in for organizational maintenance, and one or two are in for DS maintenance. Of course,

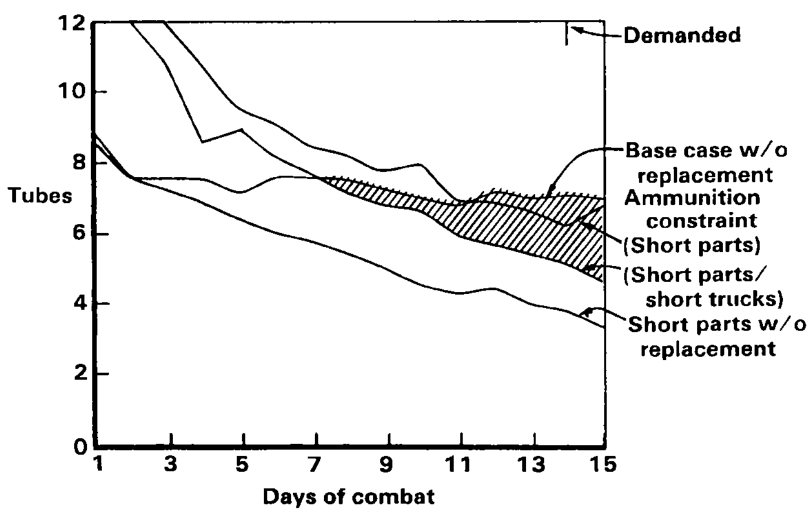

Fig. 11—Fire support missions demanded/accomplished (8-in. Bn)

[12]Recall that in the active defense SOC, the 8-in. Bn has five fire support missions during a 24-hour period. Three of those support maneuver battles, and two are counterbattery operations. The average of eight tubes per mission may, for example, be the result of a daily pattern in which the number of firing tubes goes from ten on the first mission to six on the last mission of the day.

different tubes may be in for maintenance during each fire support mission.

The artillery units require such a high volume of ammunition that it is necessary to distinguish those instances when prepositioning of munitions is allowed from those in which it is not. The curves in Fig. 11 resulted when full prepositioning of deliveries in excess of consumption was permitted. In this way, deliveries early in the simulation could be used to make up possible deficits later on. In the absence of prepositioning, the ammunition resupply system can support a level of fire support missions indicated by the curves labeled "Ammunition constraint (Short parts)" for the full TO&E complement of trucks, and "(Short parts/short trucks)" for the less-than-TO&E complement of unit trucks. In the artillery SHORTPARTS case, the sustainability of this 8-in. Bn is not limited by ammunition delivery constraints, whether or not the unit's transportation system is described by FULLTRUCK or SHORTRUCK. However, in the artillery BASE CASE, the unit's transportation system constrains output starting on Day 7, if the unit is described by SHORTRUCK, and on Day 11, if the unit is described by FULLTRUCK. In other words, output is lost in the BASE CASE without prepositioning because of ammunition delivery constraints. With partial prepositioning possible, output curves would be intermediate between the two extremes described. The sustainability implications are that it would be rational first to buy artillery spares until the point where the transportation constraint becomes binding, and then to purchase additional spares and trucks. Fuel deliveries did not constrain output in Fig. 11, and are thus not shown.

REPRESENTING THE RESULTS AS AN INDEX

It is useful to represent the effect of a resource shortfall over time by the ratio of cumulative unit output with the shortfall to cumulative unit output with some base or reference set of resources. The mathematics of such an index are more fully described in App. F. In the figures below, we chose the Base case brigade as the unit against which the output of all others was indexed. This Base case brigade had a full TO&E complement of equipment and manpower, and had unconstrained access to ammunition, POL, and spares at the DISCOM; no replacement end items were delivered to the brigade, however. Figure 12 shows the "readiness and sustainability" index for the armor components of the Short parts brigade as a function of the number of days in active defense operations. The lower curve shows that at the

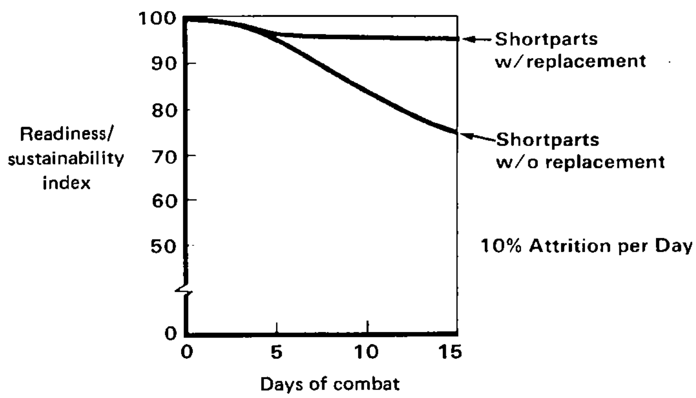

Fig. 12—Active defense SOC readiness/sustainability index with actual PLL/ASL (armor component)

end of five days the Short parts brigade without end item replacement produced 94 percent of the total output (in platoon operations or missions) of the Base case brigade, but at the end of 15 days the Short parts brigade produced only 75 percent. The higher curve shows the effect of pushing replacement tanks forward. The Short parts brigade with tanks replaced in accordance with the Table 4 schedule produced about 95 percent of the total output of the Base case brigade over any period up to 15 days.

Figure 13 shows the indexes for both artillery battalions within the Short parts brigade. Because each battalion performs a slightly different active defense SOC, we have not aggregated the indexes into a single "artillery readiness and sustainability" curve. Such an aggregation is possible by weighting each battalion's index by some measure of "military worth." In any case, the effect of a lack of spares on artillery output is vividly displayed by the curves shown. Over the 15 days of simulated operations, the 8-in. battalion produced 77 percent of the total output of the same 8-in. battalion with unconstrained spares, whereas the 155-mm battalion produced only 62 percent of the total output of its Base case counterpart. A closer examination of the conditions of the simulation reveals the reason for this poor performance. Artillery parts stockage within the constructed PLLs and ASL lacked

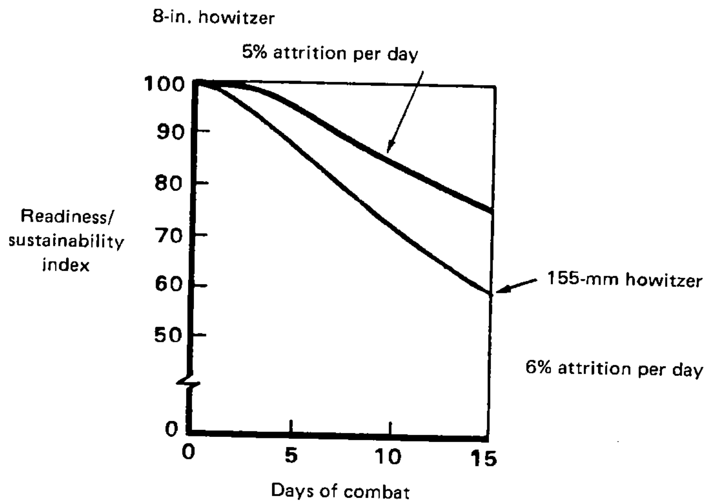

Fig. 13—Active defense SOC readiness/sustainability index with actual PLL/ASL (artillery components)

breadth,[13] and having to cannibalize a number of vehicles for parts had a substantial effect on output.

AURA BRIGADE RESULTS FOR THE ATTACK SOC

Unlike the active defense SOC, which is a series of short operations with relatively short recovery periods in between, the attack SOC is a single assault and Forward Edge of the Battle Area (FEBA) penetration, an exploitation to an objective about 20 km deep, followed by a relatively long overnight recovery period. Daily consumption of ammunition by mission capable weapons in the attack SOC we simulated was less than that for the active defense SOC (see App. B), but a number of other factors must also be taken into consideration. More mission capable tanks may participate in the battle, ammunition-carrying trucks must go further each day, and prepositioning of ammunition on the ground ahead of advancing tanks is highly impractical. Hence, supplying tanks with ammunition under these conditions

[13]See footnote 9 above.

may be more difficult. The artillery battalions not only fire fewer rounds per mission-capable tube each day, but also are highly reliant on the ability of their trucks to move ammunition over longer distances and without the benefits of prepositioning.

The attrition assumptions used in the attack SOC are shown in Table 5. For the maneuver elements of the brigade, approximately the same daily hit probability as for the active defense SOC was used, whereas for the artillery elements, a lower daily hit probability prevailed, reflecting fewer daily missions. Figure 14 shows the daily tank output per mission (in this SOC only one mission per day is demanded) for the Base case brigade and the Short parts brigade. No end items were replaced in either simulation. The curve labeled "Ammunition constraint (Short parts/Short trucks)" represents the level of tank activity that could have been supported by the deliveries of ammunition to the task forces in the SHORTRUCK case. Under the conditions of the simulation, neither the Base case brigade nor the Short parts brigade was constrained by ammunition deliveries. Individual task forces, however, faced temporary shortages. As with the active defense SOC, we can draw these conclusions with confidence only for the specific conditions of these simulations, but a principal driver of the result is the high tank attrition relative to that for the

Table 5

ATTRITION ASSUMPTIONS FOR ATTACK SOC

		Assumed Attrition Probability[a]			
Vehicle	Hit on Mission	Complete Loss Given a Hit	Complete Loss on a Mission	Hit in a Day	Complete Loss in a Day
M60A1	.10	.600	.060	.10	.06
M113A1	.051	.1755	.009	.051	.009
M109A1					
Fire support	.0133	.225	.003		
Counter-battery	.0089	.225	.002	.044	.01
M110					
Fire support	.0133	.225	.003		
Counter-battery	.0089	.225	.002	.044	.01

[a]See notes to Table 3.

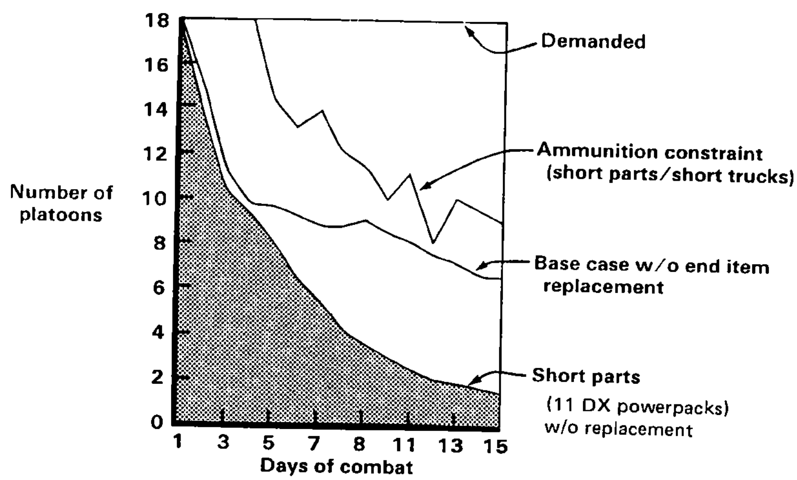

Fig. 14—Tank missions demanded/accomplished (attack SOC)

trucks. A narrowing of that difference, an increase in the consumption rate of main gun ammunition, or a flow of replacement tanks could have led to ammunition delivery constraints on tank output.

In the BASE CASE, tank output is surprisingly steady from Day 4 to Day 10 despite continued attrition. This was due largely to the return to combat of tanks damaged, but recovered, during the first three days of attack operations. In the attack SOC, significantly more tanks fall into this category than in the active defense SOC. (See App. E for recovery assumptions.)

In the SHORTPARTS case, the brigade's tank output deteriorates steadily, but perhaps more significant is the divergence of tank output after Day 4 between the BASE CASE and the SHORTPARTS case. The "readiness and sustainability index," which is shown in Fig. 15, quantifies this difference. During the first five days of operations, the Short parts brigade produces 97.5 percent of the output of the Base case brigade, but only 66 percent after 15 days of operations.

As a convenience to the reader, Table 6 summarizes the cases described in this section for brigade operations.

Table 6

MATRIX OF CONDITIONS FOR SIMULATED BRIGADE OPERATIONS IN SECTION II

		Resources and Supply							Transportation			
			Class IX (spares)			Class VIII	Class V	Class III	POL		Ammunition	
Case	SOC	Manpower	Unit	FAST	DISCOM	Major End Items	Ammunition	POL	To Brigade FDP	To Units	To ATP	To Units
BASE	Active Defense	100% TO&E	PLL	ASL-F	U	No	UC	UC	Full Truck	Full Truck	Full Truck	Full Truck
BASE + TR-1	Active Defense	100% TO&E	PLL	ASL-F	U	Yes	UC	UC	Full Truck	Full Truck	Full Truck	Full Truck
SHORTRUCK	Active Defense	100% TO&E	PLL	ASL-F	U	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
SHORTPARTS	Active Defense	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
BASE	Attack	100% TO&E	PLL	ASL-F	U	No	UC	UC	Full Truck	Full Truck	Full Truck	Full Truck
SHORTRUCKS	Attack	100% TO&E	PLL	ASL-F	U	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
SHORTPARTS	Attack	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck

NOTE: ASL-F = ASL-forward component; ASL-R = ASL-rear component; UC = unconstrained at corps; U = unconstrained; FDP = fuel distribution point.

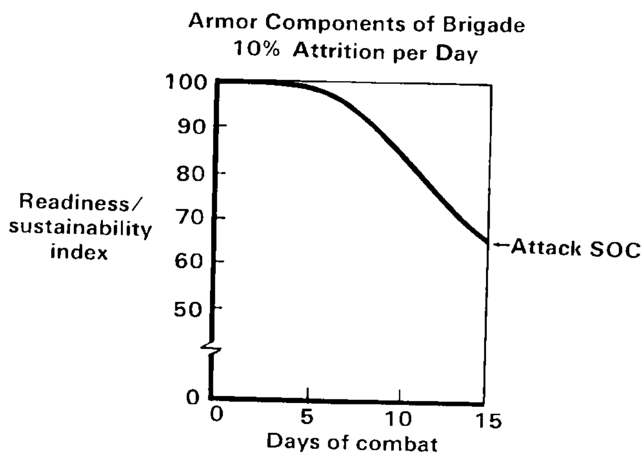

Fig. 15—Attack SOC readiness/sustainability index with actual PLL/ASL (armor component)

III. THE EFFECT OF BETTER SPARES STOCKS

The AURA simulations presented above generally demonstrated that increased stocks of spares might enhance sustainability. We asked two questions and performed two experiments in this regard. First, how much would additional stockage of certain Direct Exchange (DX) items help. Second, how much additional readiness and sustainability can be expected from the Army's Mandatory Stockage List (MSL) program. In that program, units are required to have minimum quantities of certain spares in their PLLs whether or not they are demand-supported. We will deal with each of these questions in turn.

INCREASED STOCKAGE OF M60A1 POWERPACKS

A closer look of the SHORTPARTS case for M60A1 tanks in the active defense SOC revealed that the single DX item that caused the most forgone output was the powerpack, which consists of the engine and transmission. It thus appeared most fruitful to increase the level of stockage of this DX item as a means of increasing sustainability. The earlier curves involving the SHORTPARTS case assumed a baseline of 11 spare powerpacks per brigade. This baseline is consistent with the idea that with 324 tanks in an armored division and a maintenance float of ten percent for powerpacks, a total of approximately 33 would be held at the DISCOM. With three brigades in the division, the brigade's fair share would be 11. Of course the demand for powerpacks across the division is stochastic, so some brigades might use more than their fair share, while others might use less.

To measure the effect of additional powerpacks on tank output, we simulated the Short parts brigade under the active defense SOC with 22, 33, and 99 powerpacks. Figure 16 reproduces the daily output curves for the BASE CASE and SHORTPARTS (11 powerpacks per brigade) cases, but adds the daily output curve for the SHORTPARTS (33 powerpacks per brigade) case. The additional powerpacks permit the brigade to regain about half of the forgone output that was attributable to the lack of spares. The difference begins to manifest itself after only three or four days of operations. Further increases in powerpacks alone do not add much to output. The problem then becomes the numerous other spares that have not been increased.

These results can be displayed in several ways that may be more convenient. Figure 17 shows the readiness and sustainability index for

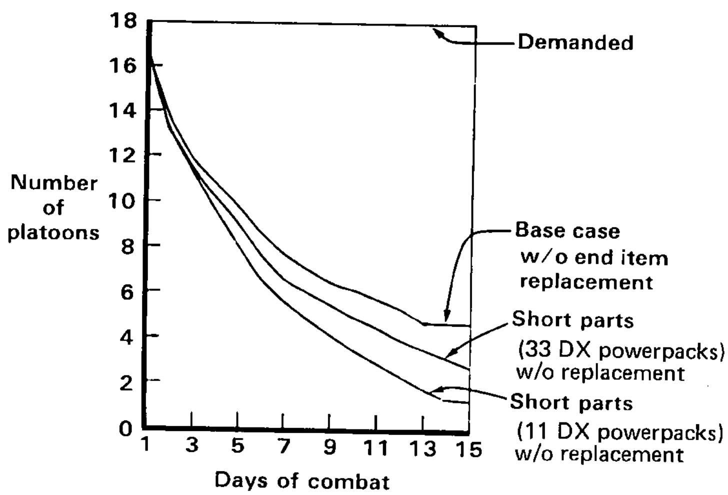

Fig. 16—Tank missions demanded/accomplished for different powerpack levels (active defense SOC)

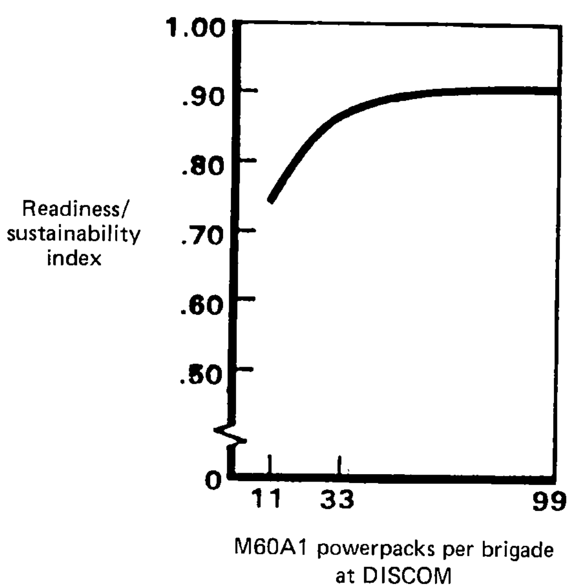

Fig. 17—Tank reliability/sustainability index vs. DX M60A1 powerpacks

the Short parts brigade for 15 days of active defense operations as a function of the number of powerpacks per brigade available at the DISCOM. At 11 such powerpacks, the brigade produces only 75 percent of the output of the Base case brigade,[1] but at 33, produces about 87 percent. The curve quickly flattens out thereafter, reflecting sharply diminishing returns.

Alternatively, one can stipulate that the tank-heavy brigades that we have simulated are "combat capable" when they are able to average at least six platoons of tanks per mission. (Generally, our simulations show this means about half of the original tanks remain.) One can then ask how many days of active defense operations does it take for a brigade to fall below this specified threshold. Figure 18 answers that question for the Short parts brigade. At 11 powerpacks per brigade, the brigade is combat capable for six and a half days; at 33, it is combat capable for about eight days. If the cost of providing these addi-

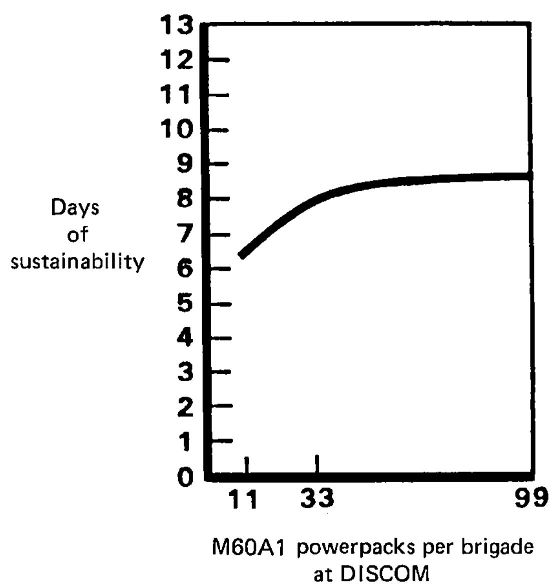

Fig. 18—Tank days of sustainability vs. DX M60A1 powerpacks

[1]This corresponds to the 75 percent point on the curve in Fig. 12.

tional powerpacks to a set of divisions were known, one could translate the above curve into one that describes days of brigade sustainability versus dollars. In Fig. 19, we have constructed such a curve by combining cost information and deployment data with Fig. 18. The cost of the M60A1 powerpack from the TACOM (Tank Automotive Command) stratification input was assumed to be the average price that would be paid.[2]

This estimated cost and the estimated quantity from Fig. 18 were applied to two sets of tank battalions: first, all M60A1/A3 battalions forward deployed in USAREUR (U.S. Army, Europe), and second, all

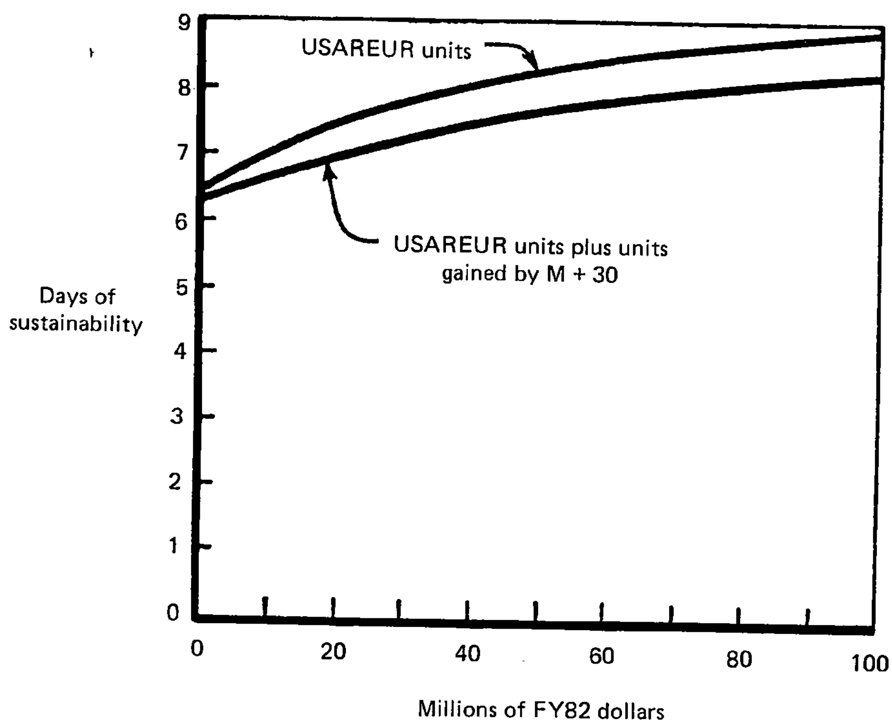

Fig. 19—Tank days of sustainability vs. POM dollars

[2]The stratification is computed each year as the basis for the Program Objective Memorandum (POM) and budget submissions for Army Stock Fund (ASF) items. For each such item, current price and purchase requirements are supposed to be maintained in the files.

M60A1/A3 battalions in USAREUR plus those scheduled to deploy to USAREUR by M+30. These sets were taken from force lists in effect as of October 1982. The two curves in Fig. 19 also exhibit diminishing returns—that is, each increment of sustainability costs more than the previous, when only powerpacks are varied. As a general rule, each increment of real resources alters the marginal contribution of all other inputs to sustainability. As we spend additional dollars on powerpacks, brigade sustainability increases, but most likely so does the sustainability impact of other resources. Indeed, the sustainability impact of these other resources may have increased so much that it makes more sense to switch additional dollars to their purchase rather than continuing to spend on powerpacks. It may also be the case that on a cost-effectiveness basis, buying additional powerpacks is not the best way to initially increase sustainability. To know what the first "buy" should be, we would need a Fig. 19 for each different resource. A "balanced" program for a given SOC is one in which the marginal contribution to sustainability of the last dollar spent on each resource is absolutely identical.[3]

THE MSL PROGRAM

The Mandatory Stockage List (MSL) program is designed to specify those spare parts that all units of a given type should have as a part of their "go-to-war" PLLs. Each MSL designates certain spares and the minimum quantity each applicable unit must have; units may determine on the basis of local demand conditions that more than these minimums are necessary. Eventually, the MSL program is designed to cover ASLs as well as PLLs, and to include an appropriate marriage of spares for unscheduled maintenance and battle damage repair. At the time of this research, the MSL program had not reached this level of implementation, and only two MSLs had been published—one for a tank company and one for a mechanized infantry company. We obtained, as part of our project, draft MSLs for a 155-mm artillery battery and an 8-in. artillery battery, and were thus able to construct an

[3]Identical marginal costs per additional unit of output is only the condition for balance among resources when the resources are infinitely divisible. A more intricate condition applies if the resources must be bought in "chunks." But more important than this, the identical marginal cost condition assumes that there is only one constraint (a budget constraint) and one measure of output that everyone agrees upon. But suppose the problem is formulated as one of demanding at least performance "X" in the active defense SOC and at least performance "Y" in the attack SOC, and doing so at minimum cost. Now there are two constraints, and the constraining resources might be different for the two SOCs. In that case, each resource would generally yield a different marginal contribution per dollar to either SOC performance measure.

approximation of a brigade's PLLs that included MSL parts and quantities for the four weapon systems in our AURA simulation.

To do that, we started with the relevant PLLs from the 3rd Armored Division, which is one of the divisions whose ASL and PLLs contributed to the "constructed" spares lists used in the research reported above. We then replaced the quantities with the maximum of (1) the MSL quantity or (2) the quantity already on hand. Naturally, for MSL items not stocked by the 3rd Armored Division's artillery and maneuver battalions, we added those items to our hypothetical PLLs and included them at the MSL quantities. In effect, these hypothetical PLLs might be what the 3rd Armored's battalions would have after adopting these early MSLs.

The 3rd Armored Division had better stockage than most of the other units on which we obtained data. We chose this as the baseline, however, for two reasons. First, being a forward-deployed unit, the 3rd Armored is going to have to depend more on its own parts stockage during the first days of combat than a later-deploying unit.[4] For it, the MSL program has added significance. Second, if the MSL-supplemented PLLs yield an improvement for the 3rd Armored Division's sustainability, then a fortiori the MSLs should improve the sustainability of a less well-stocked division in the same role.

We ran AURA with the 3rd Armored Division's PLLs and again with the MSL-supplemented PLLs, and we observed no statistically significant differences in output over time for any of the four simulated weapons—that is, we found no measurable effect of the MSL against a demand-supported PLL. These results must be viewed as tentative because, as mentioned above, the artillery MSLs were taken from draft documents, and only PLLs were supplemented with MSL items and quantities.

These results are understandable when considered in context. The MSLs we saw contained primarily high-usage, low-cost items such as tires, tracks, batteries, etc., along with some moderate cost items such as generators. Such items are already likely to be found in a well-supported demand-based PLL. Second, the MSLs so far do not include items for battle damage repair, which are being included in the Combat ASL (CASL) program. In AURA, the repair of battle damage is a major activity and consumer of parts. Third, and most important, it appears that the parts needed for wartime sustainability under current Army stockage policies are going to come from cannibalization in the field. Before elaborating on this last point, it should be noted that

[4]That is, before CONUS-based war reserve spares are moved to the theater in large quantities.

AURA can be a powerful tool in evaluating alternative parts stockage policies. It is particularly suited for use with SPARC[5] data currently being developed by the Army Materiel Systems Analysis Activity (AMSAA) and the Ballistics Research Laboratory (BRL).

CANNIBALIZATION AND SALVAGE

Figure 20 shows the scaled output of four cases for each of the four pacing weapons in the AURA simulation of the active defense SOC, with the same attrition rates (Table 3). The leftmost bar for each weapon represents the 15-day output total in the BASE CASE. Moving left to right, the next bar represents the relative output of the SHORTPARTS case. By scaling as we have here against the BASE CASE, the height of each bar is just the readiness and sustainability index used earlier. The next bar, which presents new information, is the relative output in the SHORTPARTS case when cannibalization is prohibited in the AURA simulation. The last bar is the relative output in the SHORTPARTS case when both (a) cannibalization and (b) salvage of parts from recovered but not repairable vehicles are prohibited.

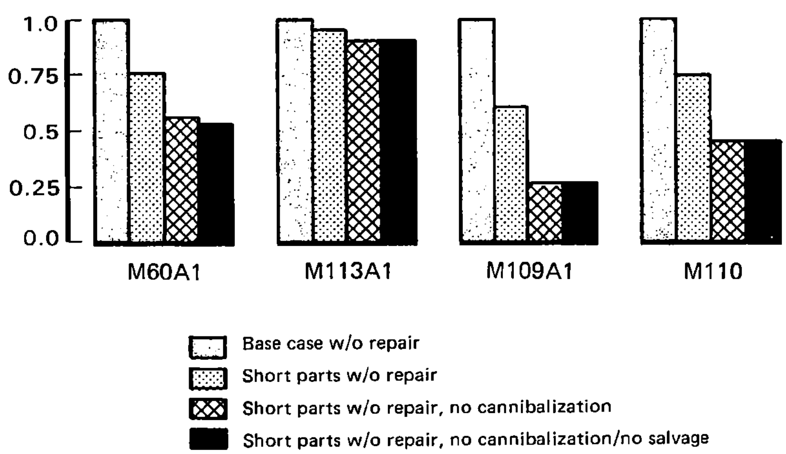

Fig. 20—Cannibalization and salvage: active defense SOC

[5]SPARC is Sustainability Predictions for Army Spare Components Requirements for Combat.

Table 7

MATRIX OF CONDITIONS FOR SIMULATED BRIGADE OPERATIONS IN SECTION III

		Resources and Supply							Transportation			
			Class IX (spares)			Class VIII	Class V	Class III	POL		Ammunition	
Case	SOC	Manpower	Unit	FAST	DISCOM	Major End Items	Ammu- nition	POL	To Brigade FDP	To Units	To ATP	To Units
BASE	Active Defense	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
SHORTPARTS (11 powerpacks)	Active Defense	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
SHORTPARTS (22 powerpacks)	Active Defense	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
SHORTPARTS (33 powerpacks)	Active Defense	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
MSL	Active Defense	100% TO&E	MSL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
No cannibal- ization	Active Defense	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck
No cannibal- ization; no salvage	Active Defense	100% TO&E	PLL	ASL-F	ASL-R	No	UC	UC	Full Truck	Short Truck	Full Truck	Short Truck

Focusing for the moment on the M60A1 portion of the figure, one observes a 25 percent decrease in cumulative output over the 15-day period for the Short parts brigade when compared with the Base case brigade. This is, of course, the same result shown in Fig. 12. Cumulative output falls another 25 percent when the Short parts brigade is not permitted to cannibalize spares from other tanks. For the artillery systems, being "short parts" has a serious effect on cumulative output, but not being permitted to cannibalize reduces output by an additional amount, roughly equal to the "short parts" amount. Not being permitted to salvage (in addition to not being permitted to cannibalize) had no measurable effect on cumulative output expected for the tank, in which case the effect is small. Attrition and recovery rates for the other pacing items are too low in the active defense SOC to yield enough spares to make a difference. In the attack SOC, salvage may very well be more important, although we have not run AURA to test that hypothesis.

The message conveyed by Fig. 20 is that cannibalization has such important implications for sustainability that it ought to be explicitly considered in spares policies and in MARC[6] (MAnpower Requirements Criteria) if a resource balance is a desired goal.

For convenience, Table 7 shows the cases examined in this section.

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[6]Formerly MACRIT, Manpower Authorization Criteria.

IV. CONCLUSIONS, PENDING ISSUES, AND FUTURE DIRECTIONS

This section summarizes our findings and raises some issues concerning the applicability of AURA to Army logistics problems.

Most models of ammunition and POL demand assume weapon availabilities that bear no relationship to the maintenance manpower and spare parts that units will actually have under intense combat conditions. AURA now has the capability to address both together. Further, AURA recognizes that deliveries to forward platoons and companies must take place at opportune times when the pace of battle permits. Other models may not do this. When these are taken into account, the AURA simulations reported here support the following conclusions subject to the caveats below.

First, ammunition MHE at the DISCOM needs to be increased to handle peak uploading periods.

Second, with full division-level transportation assets and task force transportation assets modestly below TO&E levels, the simulated brigade can be supported with ammunition and POL in the active defense SOC. This holds assuming the quantity of ammunition fired per tube, particularly for the artillery units, does not exceed by much the amounts we have chosen for the simulation. These quantities were very close to the multi-day averages in FM101-10-1, but may be significantly lower than other estimates.[1] Our conclusion also assumes that for artillery units, delivered ammunition in excess of actual consumption is prepositioned early in the campaign for later use. Also, because of the stochastic nature of the problem, a particular unit could experience a spot shortage, should it find itself, for example, with a greater-than-expected number of artillery tubes ready to fire on a given mission, and a less-than-expected number of trucks making ammunition deliveries that day.

Third, ammunition and POL resupply for the brigade in the attack SOC is more tenuous, but still feasible. Again, an increase in the number of rounds fired by mission-capable tubes much beyond our assumed value could alter this result.

Fourth, tank sustainability can be increased by having higher stocks of certain DX items, in particular, tank powerpacks. Each added day

[1]Estimates such as those in the Logistics Planning Factors or from the COSAGE (Combat Sample Generator) division-level combat model used in the WARRAMP (Wartime Requirements for Ammunition, Materiel, and Personnel) methodology.

of sustainability costs more, ceteris paribus, than the last. Our rough estimate for powerpacks from Fig. 19 is that the first incremental day for all M60A1/A3 units deploying by M+30 costs $20 million, and the second, $50 million. (Of course, it might be possible that spending less than $50 million on another resource will also produce that second incremental day.)

Fifth, we can find no measurable effect of including MSL items and quantities in a well-supported demand-based PLL (leaving the ASL demand-based as well). When the MSL program is extended to the ASL level, the overall effect can be tested with AURA.

Last, under present stockage policies, cannibalization will be an important source of spares in wartime, and that observation ought to be incorporated into MARC.

PENDING ISSUES

CMAC Data

One of the crucial inputs to AURA is data on the reliability and maintainability of the major pacing items being simulated. For these data, we have used the CMAC series of documents. The two advantages are that these documents are readily available for a wide variety of systems, and the format lends itself to a quick translation of the data to the AURA model. The principal disadvantage is that because the CMACs were based on judgmental factors and not hard data, some have legitimately questioned their validity.

Because such reliability and maintainability data are important for a variety of uses, it behooves the Army to improve the quality of this information. Recognizing this, DARCOM is working to update and improve failure rate and maintenance data at AMSAA. The AURA simulation can, of course, accept new and better data, should they become available.

Logistics Planning Factors

In the course of this research, we found that logistics planning factors differ widely depending on which Army organization is making the estimates. This means that each research team that needs such data must make an independent judgment about the "right answer." In those circumstances, it is not surprising that the number of estimates continues to proliferate. A useful product of future analysis would be a

systematic identification of logistics planning factors with their implicit and explicit assumptions.

Dollars to Readiness and Sustainability

One of the difficulties managers within DA and OSD face is the lack of a direct way to relate POM dollars to the readiness and sustainability of Army units. It is one thing to be able relate physical resources available to Army units in wartime to their readiness and sustainability in combat, as we have here using AURA. It is quite another to translate POM dollars spent on this program element or that program element to the same measures. Nor is it a matter of scaling AURA to handle larger units. This difference manifests itself in the fact that macro-level regression analysis models of dollars spent versus various traditional readiness measures, i.e., C-ratings, fail to yield consistent, much less convincing, results.

The reasons for this are complex, but can be summarized in the observation that readiness and sustainability are products not only of the requirements and budget processes, but of the distribution and execution systems that follow. All requirements systems of the magnitude the Services must operate are likely to have pitfalls, if only because of the lags in the flow of new information to them. In some cases, the basement-level details of the requirements calculations themselves leave much to be desired.

The budget execution system often leaves only the slightest trail, making it difficult to know when or if dollars in the POM actually bought what was programmed. Because the delay from the time the POM is assembled and the dollars are actually spent is at least 17 months, and usually longer, it may not even make sense to spend them as originally planned; in essence, the value of the POM is only transitory. The POM aggregates (in dollars) also cannot show what happens at the division or base level where the day-to-day readiness decisions are made.

In the distribution system, sustainability may be thwarted as well by policy decisions that make perfect sense when viewed from an individual organization's perspective. Obviously, the AURA simulation cannot solve all of these problems. To begin to address them requires a system-wide approach, starting perhaps with the PPBS (Planning, Programming, and Budgeting System) itself.

AURA Implementation

AURA is operational at The Rand Corporation and at the U.S. Army Materiel Systems Analysis Activity (AMSAA) on an IBM 370/3032 and VAX 11/780, respectively. The AURA source code is available to qualified DoD users along with a two-volume User's Manual and a data base guide. Applications of AURA in addition to those reported here are numerous and may require that the model be installed at additional locations.

To use AURA for additional applications means that an appropriate data base must be assembled, but that is a consideration apart from having the model itself implemented at a particular installation. One might contemplate using AURA in its present form to integrate SPARC data with regular maintenance and repair data, to validate combat PLLs and ASLs, or to make manpower and spare parts recommendations following a new weapon's operational test. Further, one might contemplate using AURA to estimate the sustainability of a Soviet division in a NATO-Warsaw Pact conflict, or to create a data base to answer a variety of "what if" questions about the sustainability of a Marine Amphibious Force.

FUTURE DIRECTIONS

Future directions for AURA lie in using AURA's great mass of logistical detail at the brigade and division level to study sustainability at the theater level, and in improving the model to handle previously ignored circumstances. We shall consider each of these in turn.

With AURA, we can simulate in great detail logistics operations of a brigade or group of brigades within a division structure, but that is not sufficient to say how a group of brigades will fare in a theater. One reason is that theater forces are changing constantly, as for example when new units arrive from CONUS. Another is that AURA has no way of knowing what any particular brigade is doing at a given moment—that is, what SOC each brigade is conducting. That SOC depends on theater-wide factors, the prior history of the conflict up to that point, and on the enemy's forces and strategy. Nevertheless, it would seem possible to use AURA in much the same way a high resolution model is used in conjunction with a low resolution theater model in the WARRAMP (Wartime Requirements for Ammunition, Materiel, and Personnel) methodology. Such a system would require a number of model interfaces and report generators. In return, it would provide a plausible projection of resource drawdowns on a theater-wide basis.

There are a number of improvements that might be made to AURA, both on general grounds and for analyses involving special circumstances. At the present time, AURA permits only one type of POL in a given simulation, salvage time is not charged to maintenance personnel, and cross-trained personnel must be specified at the beginning of a run. We might therefore want to revise the code to allow for more than one type of POL, or to charge maintenance personnel for salvage time in the same way as cannibalization time is charged, or to permit cross-training during a particular run.

Rand is attempting to introduce the possibility of chemical attack on rear areas in the simulation. That effort is first being implemented on TSAR, AURA's progenitor, but will eventually be available to AURA users. Chemical attacks create both immediate and long-lasting effects on logistic operations, and they require decontamination before regular activities can resume. These special circumstances make it necessary to alter the simulation itself. With the current concern in NATO about how to deal with Soviet offensive chemical capabilities, this addition to AURA should provide an opportunity for new insights into logistic constraints in a chemical environment. Other special improvements to AURA are also possible.

Appendix A

ARMY UNIT READINESS/SUSTAINABILITY ASSESSOR (AURA)

The AURA (Army Unit Readiness/Sustainability Assessor) model is a derivative version of a Rand model that is now coming into use by its sponsor, the U.S. Air Force. The original model, called TSAR (Theater Simulation of Airbase Resources), was adapted to handle the special requirements of combined arms units. AURA simulates a system of interdependent theater-wide units/bases supported by an intratheater resource management system. By capturing the interdependencies among resources, AURA permits decisionmakers to examine the implications of alternative resource levels on mission output levels for combat units, and to assess a broad range of policy options that may affect resource allocation decisions on a theater-wide basis. AURA also allows examination of the effects of attrition, replenishment, and higher-echelon repair on continued operations.

AURA ARCHITECTURE

Eleven classes of resources are treated in the simulation including weapons, crews, support personnel, tools, support equipment, spares, munitions, POL, and organizational facilities. Each of these broad classes of resources may be divided into many individual types, with some limitations.[1] Spare parts may be specified by the user, or, if ordered, the model will compute a parts list according to standard algorithms.[2]

AURA is a Monte Carlo event simulation model that has been designed for analyzing the interactions between resources and the capability of units to generate operations in a rapidly evolving wartime environment. On-vehicle maintenance tasks are simulated for several units simultaneously. The model is readily adaptable to problems across a broad range of complexity. When specific features are not

[1]Only eight types of crews and weapons systems and one type of facility and POL are currently permitted in any particular simulation.

[2]In other words, the model will generate a PLL (Prescribed Load List) and ASL (Authorized Stockage List). With a credible battle damage generator, the model could be used to create a combat PLL or ASL.

needed in a particular problem, they simply are not used. Thus, the model permits the analyst to represent either a single unit, a set of independent units, or a set of interdependent units without any adjustment or modification of the program. Similarly, if the user does not wish to examine the effects of unit losses, or of shortages of facilities, maintenance personnel, tools, spare parts, munitions, or fuel, no special precautions are needed as the model adapts automatically to all such problem representations.

AURA has also been designed with an analytic structure that permits examination of a wide variety of potential improvements in unit resource allocation and organization in a common context. New maintenance doctrines, modified manning levels, increased stock levels for parts and equipment, and a variety of concepts for theater-wide resource management can be examined with the model in terms of their effects on the system's ability to generate missions.

An important objective in the original design formulation was to achieve a sufficiently high speed of operation that the extensive sequence of runs so frequently necessary in research and analysis would be economically practical. Adaptation of existing models was rejected because of the prohibitive costs of modifying these programs and using them on a regular basis for problems of the size that were contemplated. The resulting custom-designed program, written in the widely available FORTRAN language, achieves a substantially higher speed by virtue of more efficient processing and by taking advantage of the recent dramatic increases in the size of the core storage of modern computers. The current formulation makes no intermediate use of auxiliary high-speed storage units (e.g., disks, tapes) except for storing the initial conditions for multiple trials.

In the model, specified numbers of weapon systems (usually vehicles) of various types (e.g., tanks, armored personnel carriers) can be assigned to each unit, usually a battalion. These weapons may be supported by a common pool of resources (e.g., personnel, spares), or may be organized into two or three subgroups (usually companies) each supported by its own set of resources. Thus, the model offers a natural way of treating the Army's multi-echelon support organizations—general support (GS), direct support (DS), and organizational maintenance.

OPERATIONS

The vehicles are readied for operations and massed for employment in response to a set of user-supplied operational requirements, differentiated by unit, vehicle type, operation length, and priority. These user-supplied operational requirements are called missions. If a unit is not specified, the operation demands are allocated to the unit next best able to fulfill them. Missions may be scheduled or organized for continuous or contingency action as required by the user. Returning vehicles not destroyed, both damaged and serviceable, may still have unexpended munitions and may have unscheduled or scheduled maintenance requirements. The inputs that govern such probabilities for maintenance other than battle damage repairs—the break rates—may be either a fixed rate per operation or varied daily by work center (shop) or vehicle type as a function of the operations rate or other user-specified activity function (e.g., miles driven, rounds fired, days on the line). If a vehicle is damaged or destroyed, a replacement can be resupplied immediately or resupplied after a delay approximating wartime replacement conditions.

The next assignment for each unit is selected as the previous operation tasks are completed. The selection takes into account the known requirements for the next operation and the unit's remaining capability to meet the requirement. It also depends on the unit's ability to generate weapons configured for the next operation. All maintenance and replenishment tasks not essential for the next operation may be deferred and the available resources concentrated on required tasks. If a vehicle is not required for the next operation, it may be reassigned or reconfigured[3] for a more appropriate operation.

MAINTENANCE AND SPARES

Vehicle maintenance can be divided into scheduled and unscheduled tasks; AURA treats both. The scheduled requirements include (1) periodic maintenance, performed at specified intervals of time, (2) certain essential support tasks, (3) reloading basic munitions, and (4) pre-mission maintenance tasks (loading mission-dependent ammunition and refueling) prior to each mission.

Unscheduled maintenance tasks develop at random or are generated in battle; the former are categorized as required or deferrable, on a mission-by-mission basis. Deferrable tasks may be completed after

[3] An example is a truck converted from an ammunition or cargo carrier to a POL truck by the addition of a bladder.

some number of missions, before the next day's activity, or they may be deferred indefinitely if mission requirements do not require their completion. For some tasks it may be required that the vehicle be moved to a better-equipped support unit, presumably located further to the rear.

On-vehicle maintenance tasks may require a number of specialists, specialized support equipment, and a spare part; each task is either a single set of such requirements—a simple task—or a network of tasks, each with its own demand for personnel and equipment. (See N-1987-MRAL, *AURA User's Manual,* Vol. I, pp. 23–27, for a description of task networks.) When resources are limited, those vehicles most likely to be readied first (given on-hand resources) may be given priority.

When a vehicle breaks or is damaged during a combat mission, the model goes through the following general procedure: those vehicles needing a tow are identified and support resources are allocated either from the unit itself or from a supporting unit. An estimate is made of the time and resources needed to fix each vehicle and maintenance personnel (e.g., organizational or contact teams) are assigned along with other maintenance resources to those vehicles meriting priority. Crews are rested and fed between missions, but must also perform certain daily maintenance checks, reload their vehicles, and refuel them. They may need to perform certain maintenance tasks themselves. Vehicles are recycled, and, at the time called for in the operations plan, reconstituted into combat units, usually platoons. In AURA's logic, those vehicles that do not have mission-essential subsystems working, or do not have crews, sufficient ammunition, and POL cannot be sent into battle. In AURA, vehicles are "down" because a resource (e.g., a part) could not be applied in time to meet the operational demand.

If a required part is not available, (1) the broken one that is removed may be repaired within the unit, (2) the appropriate part may be cannibalized from another vehicle, (3) a part may be resupplied from a specified subset of units (usually a FAST or DISCOM), or (4) the part may be ordered from a central source within the theater. If a part cannot be repaired in the unit—that is, Not Reparable This Station (NRTS)—it may be sent to a neighboring unit or to a centralized facility in the theater designated to perform intermediate maintenance. If a part cannot be repaired within the theater, a replacement may be requested from a depot in CONUS. AURA is the only Army model that treats deferred maintenance, cannibalization, unscheduled maintenance, and battle-damage repair in a common framework.

Each maintenance task and parts repair job is accomplished by the personnel and equipment associated with a particular work center, or "shop." The user may group the resources and tasks into as many as 25

different shops, exclusive of those associated with the scheduled pre- and post-mission maintenance tasks. Because each shop may be assigned several different types of personnel and equipment, those engaged in on-vehicle and off-vehicle tasks may be the same or different depending upon how the user wishes to define the unit's maintenance policies.

The user is given substantial flexibility in defining the rules by which maintenance tasks are processed. The user may permit the activities of certain groups of shops to proceed simultaneously or may require that the activities of several such groups of shops proceed in a specified order. The user may also control these proscriptions for simultaneous and sequential operations separately for each vehicle type at each unit. Furthermore, for groups of shops that may proceed simultaneously, certain exceptions may be specified in the form of lists of activities that are incompatible with each task. These features permit alternative work load management doctrines to be examined for their influence on mission generation capabilities. Work speed-up and other procedures to shorten on-vehicle, pre-mission, and off-vehicle activities also may be specified.

Scheduled pre-mission tasks are also associated with the shop structure. These tasks involve vehicle refueling and the loading of ammunition. The likelihood that munitions are left over from the previous operation can be specified independently for each type of ammunition. After mission assignment, vehicle configuration is checked, and, if necessary, it is reconfigured; this may involve one or two separate tasks, each of which may require personnel and equipment. The loading of the mission-dependent ammunition also may involve one or two separate tasks, each with its distinct requirements.

Several features are included that permit the user to simulate various "work-around" procedures that can alleviate resource constraints. One such feature permits the user to specify alternative resource requirements for any unscheduled on-vehicle task, parts repair job, or an ammunition loading job; for example, one might specify that a three-man crew could do a normal four-man job in 50 percent more time. Similarly, if ammunition shortages do not permit the normal, or preferred, ammunition to be loaded for a mission, several alternative loadings may be specified. A third "work-around" feature permits the user to designate certain types of personnel as having been cross-trained so that they can replace or assist certain other specialists. This personnel substitutability feature is operative only for specified units and on specified on-vehicle tasks, or munitions loading tasks.

DAMAGE TO LOGISTICS UNITS AND FACILITIES

A special version of the AIDA (AIrbase Damage Assessment) model is included in AURA as a general-purpose damage assessment tool. This subroutine accepts detailed (if desired) descriptions of the size, location, and vulnerability of various logistics units, supply dumps, and maintenance facilities, as well as specifications of enemy attacks and weapons effectiveness factors (from the *Joint Munitions Effectiveness Manual*). When used with AURA, enemy attacks on rear support areas can be incorporated in the same Monte Carlo fashion to determine the effects on the ability of units to generate missions.

DISTRIBUTION AND TRANSPORTATION

In addition to simulating a set of units, the user may specify a centralized theater distribution center or a centralized theater repair facility at which some or all intermediate maintenance is conducted. The centralized distribution facility can receive spare parts from CONUS and either retain them until demanded by a unit or transship (some or all) to the unit with the earliest projected requirement. Such a facility can also direct the lateral shipment of parts and other resources from one unit to another. The repair facility, such as a GS Corps Support Command (COSCOM) Center, has maintenance personnel, equipment, and spare parts. Parts are shipped to and from the COSCOM from the operating units and are processed in the manner prescribed by the user's choice of theater management rules to govern these operations.

The simplest rules for Corps Support Command or Division Support Command (DISCOM) operation prescribe that faulty parts are repaired in the order in which they arrive and that they are returned to the sender. The user may also invoke a variety of more complex management algorithms, not only for selecting what to repair and how to dispose of parts when they have been repaired, but for reallocating personnel, equipment, and parts among the several operating units. Repair priorities can be based on existing and projected demands and on the relative importance of parts for the various missions. Shipment priorities are related to the current and projected demands, in-unit reparables, and enroute serviceables. When central stocks are insufficient to meet a unit's demand, another unit can be directed to ship the required part, if both the requesting unit and the donor unit meet certain conditions concerning the importance of the demand and the availability of stock.

Daily estimates can be prepared for each unit's capabilities for generating different kinds of operations with different types of weapons

(e.g., tanks). These estimates provide the basis for various unit management decisions. One application is in selecting which unit is to be assigned an operation for which no unit has been specified. These data can also be used to support assignment decisions when vehicles must be diverted and when vehicles are transferred from unit to unit.

THEATER MANAGEMENT

The theater-wide management of the various resources is supported by a user-specified scheduled transportation system that may be subjected to delays, cancellations, and losses. The model also permits the user to represent a theater-wide reporting system to provide the central management authority with periodic resource status reports from the several operating units; these reports may be delayed, incomplete, or lost.

When these transportation and communication systems are coupled with the sets of rules for distributing and redistributing resources among the operating units, various concepts of theater resource management may be represented and examined in the context of realistic transportation and communication imperfections. In its current formulation, the model already includes certain alternatives for the theater management rules and has been designed to facilitate additions or modifications.

Appendix B

ACTIVE DEFENSE AND ATTACK SOCS

The attack SOC usage profile, shown in Fig. B.1, is conducted by each of the brigade's tank-heavy task forces. Each task force moves to an assembly area at 0600 hours, penetrates enemy lines, seizes an objective several kilometers away, and consolidates its position. The hour shown for each completed task in the schematic represents expected value. The time to exploit was made a random variable drawn from a uniform distribution of one to seven hours. The consumption rates shown in Table B.1 represent the typical expenditure of ammunition and fuel by a tank and an armored personnel carrier. Cross-leveling, the practice of distributing remaining resources evenly among units at the end of the operation, would even out any variations. We obtained these consumption rates in discussions with brigade and battalion commanders in FORSCOM and USAREUR.

In this usage profile, the fuel consumed during operation and subsequent recycling is about 28 percent of the full fuel load of the M60A1 tank and about 30 percent of that of the M113A1 personnel carrier. (These fuel-consumption[1] figures were obtained from the 1st Cavalry Division, Ft. Hood, Texas.) About 60 percent of the tank's 105-mm ammunition load is fired during the operation.

The active defense SOC usage profile calls for three operations by each of the brigade's three task forces in a 24-hour period. Over that time each task force engages in three positional defense battles, two rearward redeployments, and one hasty counterattack. The sequence of events is shown in Figs. B.2 through B.4.

Starting at 0600, the task force defends an initial set of battle positions (BP1) against an enemy force, and then withdraws about 6 km to a second set of prepared battle positions (BP2) where the task force is replenished and reconstituted. This redeployment is completed at approximately 0820. At 1300 (Fig. B.3), the task force is again attacked by another enemy force, presumably a second-echelon regiment.

The task force defends BP2, and then launches a hasty counterattack, recovering some of the terrain it gave up in the morning. At 2000

[1]Fuel consumption rates are shown in Tables B.1, B.2, B.3, and B.4 as gallons/kilometer while moving and gallons/hour while idling.

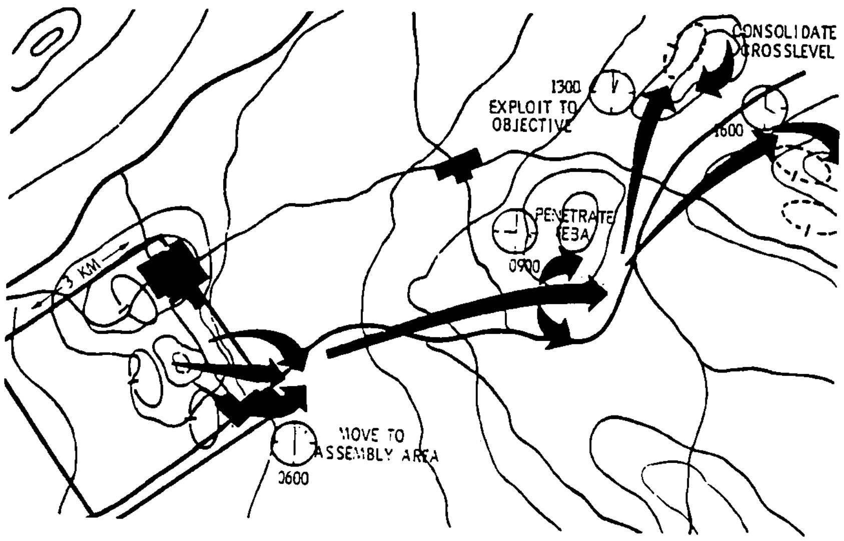

Fig. B.1—The attack SOC usage profile

Table B.1

ATTACK SOC CONSUMPTION RATES

Mission Component	Distance (km)	Time (hr)	Engine Time (hr)	Fuel (gal/km) (gal/hr)	Fuel (gal)	Ammunition (rds) 105-mm	30-cal	50-cal
Movement to assembly area								
M60A1	10	2.0	2.0	1.3	13.0	0	0	0
M113A1				.27	2.7	—	—	0
Penetration/roll flanks								
M60A1	4	1.0	1.0	2.25	910	24	500	200
M113A1				.4	1.6	—	—	400
Exploit to objective								
M60A1	40	4.0	4.0	1.3	52.0	16	500	100
M113A1				.27	10.8	—	—	300
Consolidate								
M60A1	1	1.0	1.0	1.3	1.3	0	500	0
M113A1				.27	.27	—	—	300
Cross level								
M60A1	—	2.0	2.0	5.0	10.0	0	0	0
M113A1				1.5	3.0	—	—	0
Recycle								
M60A1	—	14.0	4.0	5.0	20.0	0	0	0
M113A1				1.5	6.0	—	—	0
Total								
M60A1	55	24.0	14.0	—	105.3	40	1500	300
M113A1				—	24.4	—	—	1000

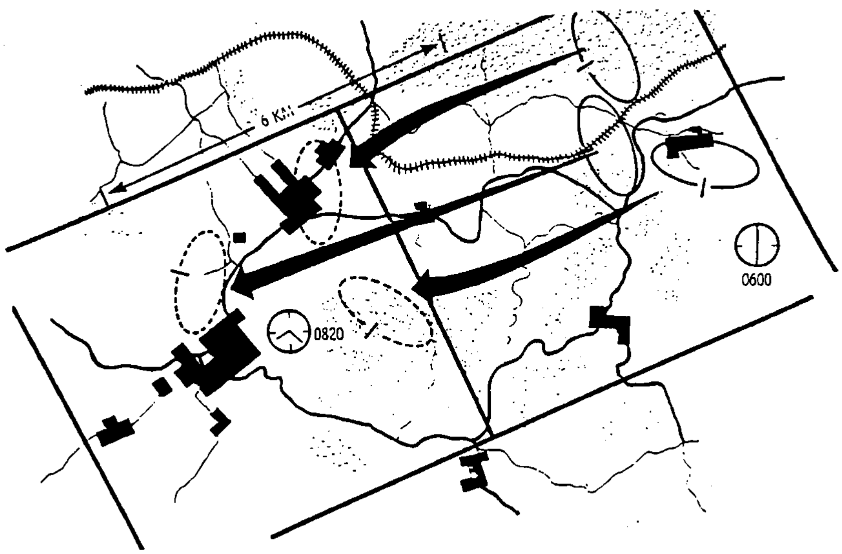

Fig. B.2—The active defense SOC usage profile, Phase I

(Fig. B.4), the task force is again assaulted, and after defending its battle positions, withdraws to BP2. Operations end for the day at approximately 2220 with a net loss of 6 km. Average time between operations is approximately 4.7 hours during the day, and 7.7 hours overnight.

Consumption rates for each operation in the active defense SOC are shown in Table B.2. Multiplying the fuel and ammunition figures by three to reflect a daily rate reveals that slightly less fuel and significantly more 105-mm ammunition is used in the active defense SOC than in the attack SOC. At these consumption rates, over the three operations each day, the typical M60A1 shoots all of its on-board main gun ammunition.

Artillery units that support the task forces in the attack and active defense SOCs perform both fire support missions and counterbattery missions. The primary differences between the usage profiles in the attack SOC and active defense SOC for these artillery units are in the number and mix of the two types of missions.

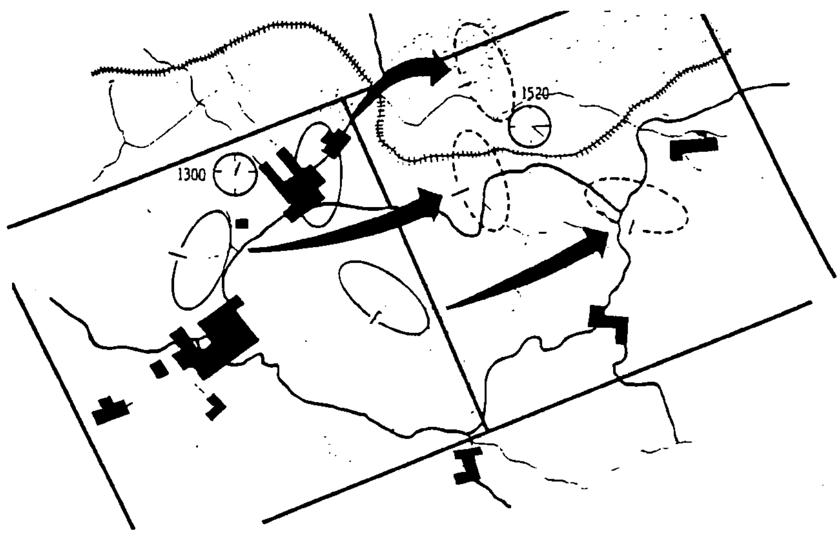

Fig. B.3—The active defense SOC usage profile, Phase II

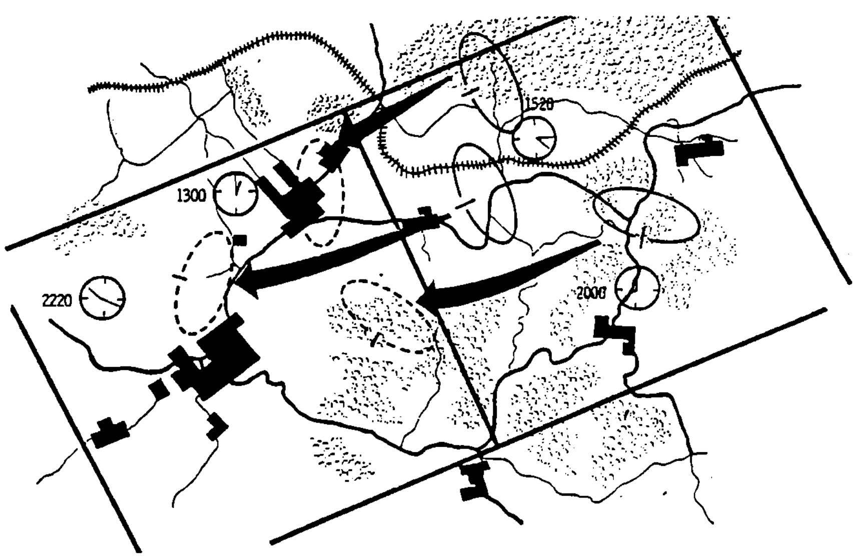

Fig. B.4—The active defense SOC usage profile, Phase III

Table B.2

ACTIVE DEFENSE SOC CONSUMPTION RATES

Mission Component	Distance (km)	Time (hr)	Engine Time (hr)	Fuel (gal/km) (gal/hr)	Fuel (gal)	Ammunition (rds) 105-mm	30-cal	50-cal
Defend BP-1								
M60A1	3	1.5	1.5	2.25	6.75	21	500	200
M113A1				.4	1.2	—	—	330
Relocate to BP-2								
M60A1	10	0.5	0.5	1.3	13.0	0	500	100
M113A1				.27	.27	—	—	0
Deploy/cross level								
M60A1	—	0.3	0.3	5.0	1.5	0	0	0
M113A1				1.5	.45	—	—	0
Recycle								
M60A1	—	4.7	2.35	5.0	11.75	0	0	0
M113A1				1.5	3.5	—	—	0
Total								
M60A1	13	7.0	4.65	—	33.0	21	1000	300
M113A1				—	7.85	—	—	330

In the attack SOC, each type of artillery unit—the 155-mm and 8-in. battalions—performs two fire support missions and two counterbattery operations in a 24-hour period. The fire support missions support the maneuver units during their initial penetration of the FEBA and then again during their capture of the final objective. In between, each artillery unit performs a counterbattery mission against enemy artillery. Recycling and maintenance takes place during those periods when the unit is not moving or engaging the enemy.

Tables B.3 and B.4 show the consumption of ammunition and POL for the two types of missions. Total SOC consumption rates per day depend on the precise number of each of the missions. In the attack SOC, for example, with two of each, a 155-mm battalion would fire an average 140 rounds per tube and the 8-in. battalion would average 100 rounds per tube.

In the active defense SOC, the 155-mm battalion performs six missions per day—three of each kind. The 8-in. battalion performs three fire support missions and two counterbattery operations.

Both types of units support the maneuver battles that are depicted in Figs. B.2 through B.4—the morning, midday, and evening engagements. The counterbattery operations occur at times in between these

Table B.3

ACTIVE DEFENSE AND ATTACK SOC ARTILLERY CONSUMPTION RATES
(Fire support missions)

Mission Component	Time in Position (min)	Movement Distance (km)	Movement Time (min)	Engine Time[a] (min)	Fuel Rate[b] (gal/hr) (gal/km)	Fuel (gal)	Ammunition[c] Fired per Tube
At FP1							
M109A1	75	—	—	83	5.0	6.9	20
M110							15
Move to FP2							
M109A1		8	32	32	.589	4.7	—
M110					.413	3.3	
At FP2							
M109A1	28	—	—	38	5.0	3.2	10/15
M10							10
Move to FP3							
M109A1		2	12	12	.589	1.2	
M110					.413	.8	
Recycle/Lager	90	—	—	45	5.0	3.75	—
Total							
M109A1	193	10	44	210		19.8	30/35
M110						17.8	25

[a]Includes deployment time of 2 min before firing and 8 min after firing.
[b]Fuel consumption (gal/km) figures from FM101-10-1; gal/hr figure based on discussions with III Corps at Fort Hood, Texas.
[c]If two figures are given, the first is for the active defense SOC and the second is for the attack SOC.

maneuver battles. Figures B.5 and B.6 depict the usage profile of an 8-in. battery. Starting from FP1 (firing point 1), the battery supports (DS/R) a maneuver task force starting at 0600. The first fire support mission ends at approximately 0845; at 1030 the first counterbattery operation begins. At 1300 (Fig. B.5), the units support the midday maneuver battle and perform counterbattery work at 1730. At 2000, a fire support mission is needed again.

During a 24-hour period, the battery may move up to eight times as a result of FEBA changes and for its own survivability. In the active defense, a 155-mm battalion will fire on average 180 rounds per tube and consume almost 100 gallons of fuel per tube. An 8-in. battalion will fire approximately 125 rounds per tube and use slightly less fuel. Fuel consumption in both cases is approximately 50 percent of the full on-board fuel load.

Table B.4

ACTIVE DEFENSE AND ATTACK SOC ARTILLERY CONSUMPTION RATES
(Counterbattery missions)

Mission Component	Time in Position (min)	Movement Distance (km)	Movement Time (min)	Engine Time[a] (min)	Fuel Rate[b] (gal/hr) (gal/km)	Fuel (gal)	Ammunition[c] Fired per Tube
At FP1							
M109A1	22	—	—	30	5.0	3.2	30/35
M110							25
Move to FP2							
M109A1		10	40	40	.589	5.9	
M110					.413	4.1	
Recycle/Lager	105	—	—	52	5.0	4.3	
Total							
M109A1	127	10	40	122		13.4	30/35
M110						11.6	25

[a]Includes deployment time of 2 min before firing and 8 min after firing.

[b]Fuel consumption (gal/km) figures from FM101-10-1; gal/hr figure based on discussions with III Corps at Fort Hood, Texas.

[c]If two figures are given, the first is for the active defense SOC and the second is for the attack SOC.

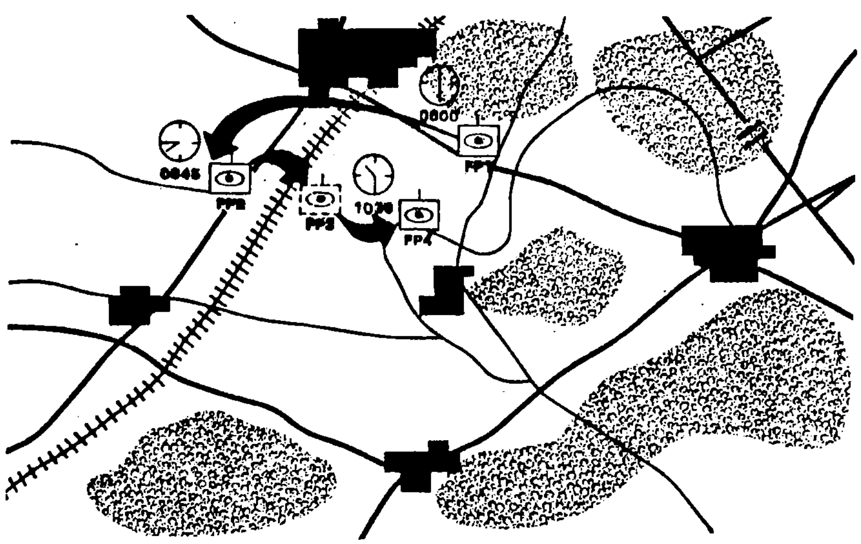

Fig. B.5—The active defense SOC usage profile—8-in. battalion, Phase I

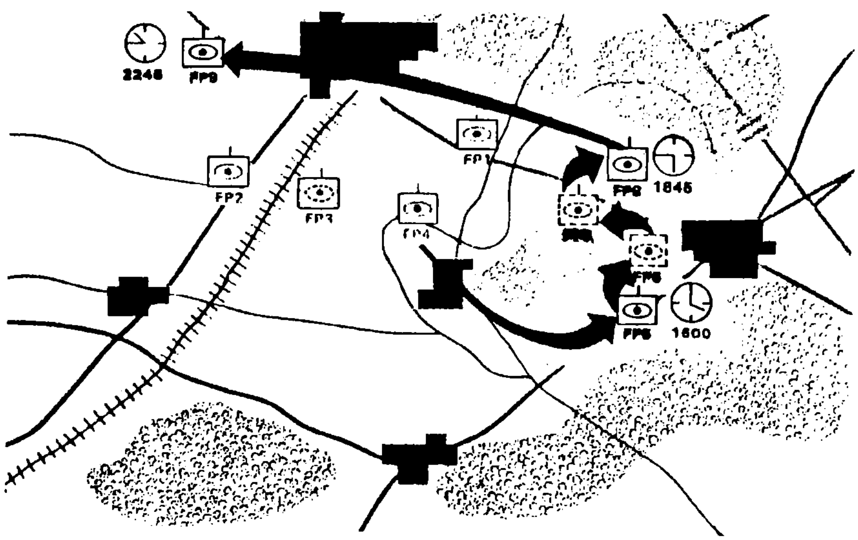

Fig. B.6—The active defense SOC usage profile—8-in. battalion, Phase II

Appendix C

AMMUNITION REQUIREMENTS CALCULATIONS

Table C.1

AMMUNITION REQUIREMENTS CALCULATION FOR TANK AND MECHANIZED INFANTRY BATTALIONS[a]

		First Day			Succeeding Days		
Weapon	Number of Wps	Rds/Day/ Wp	S.ton/Day/ Wp	Total S.tons	Rds/Day/ Wp	S.ton/Day/ Wp	Total S.tons
		Tank Battalion in Defense of Position					
Main gun	54	63	2.048	110.59	63	2.048	110.59
50-cal	94	263	.052	4.88	159	.031	2.95
30-cal	54	649	.030	1.62	393	.018	.94
4.2-in.mortar	4	163	3.260	13.04	99	1.980	7.92
81-mm mortar	—						
TOW	—						
Dragon	—						
Grenade launcher	—						
45-cal submg	122	44	.001	.11	27	<.001	.07
5.56-mm R40	254	148	.003	.79	90	.002	.48
		Mechanized Infantry Battalion in Defense of Position					
Main gun							
50-cal	116	263	.052	6.02	159	.031	3.64
30-cal	63	649	.030	1.89	393	.018	1.15
4.2-in.mortar	4	163	3.260	13.04	99	1.980	7.92
81-mm mortar	9	145	1.256	11.30	88	.762	6.86
TOW	18	16	.696	12.53	10	.435	7.83
Dragon	27	6	.201	5.43	4	.134	3.62
Grenade launcher	91	32	.012	1.09	19	.007	.65
45-cal submg	12	44	.001	.01	27	<.001	.01
5.56-mm R40	705	148	.003	2.11	90	.002	1.29

[a]All data from FM101-10-1 (Table 3-27) except for main gun ammunition, which uses active defense SOC consumption rates.

Table C.2

AMMUNITION REQUIREMENTS CALCULATION FOR ARTILLERY BATTALIONS

Unit	Number of Weapons	Rds/Day/Wp[a]	S.tons/Day/Wp[b]	Total S.tons
155-mm howitzer Bn	18	180	12.22	220.0
8-in. howitzer Bn	12	125	16.41	196.9

[a]Active defense SOC consumption rates. Weight of 50-cal machine gun rounds is negligible.
[b]From FM101-10-1; includes fuse, primer, and propelling charge.

Table C.3

AMMUNITION REQUIREMENTS CALCULATION FOR MANEUVER TASK FORCE[a]

	First Day		Succeeding Days	
Weapon Class	Short Tons	Fraction	Short Tons	Fraction
105-mm main gun	73.73	.70	73.73	.79
Mortars	16.81	.16	10.21	.11
Missiles	5.99	.06	3.82	.04
Other	8.64	.08	5.23	.06
Total	105.17	1.00	92.99	1.00

[a]Two-thirds of tank battalion rates plus one-third of mech infantry battalion rates from Table C.1.

Appendix D

FUEL REQUIREMENTS CALCULATIONS

Table D.1

POL REQUIREMENTS CALCULATION FOR TANK AND MECHANIZED INFANTRY BATTALIONS

Equipment Type	Number	Km/Day[a]	Gal/Day/ Item[b]	Total Gal/Day
Tank Battalion in Active Defense SOC				
M60A1 tank	54	39	99	5346
M113A1 APC	28	39	23.6	659
2-1/2t truck	12	60	7.8	94
	9	220	28.8	259
5t truck	6	60	27.5	165
8t truck	5	60	33.0	165
2500-gal fueler	4	60	33.0	132
10t truck	1	30	6.2	6
M88 ARV	5	30	12.6	63
Other	—			480
Stationary	—			144
Total				7513
from LPF				26389[c]
Mech. Infantry Battalion in Active Defense SOC				
M60A1 tank				
M113A1 APC	102	39	23.6	2402
2-1/2t truck	10	60	7.8	78
	9	220	28.8	259
5t truck	6	60	27.5	165
8t truck	5	60	33.0	165
2500-gal fueler	2	60	33.0	132
10t truck	1	30	6.2	6
M88 ARV	2	30	12.6	25
Other	—			672
Stationary	—			120
Total				4024
from LPF				9584[d]

[a]From active defense SOC.
[b]From FM101-10-1.
[c]For SRC 17-035HO.
[d]For SRC 7-045HO.

Table D.2

POL REQUIREMENTS CALCULATION FOR ARTILLERY BATTALIONS

Equipment Type	Number	Km/Day[a]	Gal/Day/ Item[b]	Total Gal/Day
155-mm Bn Supporting Active Defense SOC				
M109A1 howitzer	18		96.6	1739
M110 howitzer	—			
M548 ammo carrier	18	30	9.0	162
M113A1 APC	18	30	7.5	135
2-1/2t truck	10	30	2.8	28
	9	110	10.3	93
5t truck	3	30	13.8	41
8t truck	18	60	33.0	594
2500-gal fuelers	2	30	16.5	33
10t truck	1	30	6.2	6
Other	—	—	—	420
Total				3251
from LPF				6854[c]
8-in. Supporting Active Defense SOC				
M109A1 howitzer				
M110 howitzer	12		95.8	1150
M548 ammo carrier	12	30	9.0	108
M113A1 APC	12	30	7.5	98
2-1/2t truck	10	30	2.8	28
	9	110	10.3	93
5t truck	4	30	13.8	55
8t truck	18	60	33.0	594
2500-gal fuelers	—	—	—	—
10t truck	1	30	6.2	6
Other	—	—	—	420
Total				2552
from LPF				5522

[a]From artillery active defense DS SOC.
[b]From FM101-10-1.
[c]For SRC 6-365H and 6-395H, respectively.

Table D.3

POL REQUIREMENTS CALCULATION FOR MANEUVER TASK FORCE[a]

Equipment Type	Total Gal/Day	Fraction
Tracked	4854	.76
Wheeled	816	.13
Other	680	.11
Total	6350	1.00

[a]Two-thirds of tank battalion rates plus one third of mech infantry battalion rates from Table D.1.

Appendix E

ATTRITION, RECOVERY, AND BATTLE DAMAGE PROBABILITIES

AURA treats attrition with a specific logic that encompasses outright loss of vehicles, loss of mobility, recovery, level of repair, and salvage. One form of organization of this material appeared in a previous report on this project[1], and is reproduced here.

The net attrition rate must account for all vehicles with permanent damage except those recovered and salvaged, plus those temporarily damaged but nevertheless left on the battlefield.

Within a given SOC (attack or active defense), missions for tanks and APCs do not have different attrition parameters for morning, midday, or afternoon missions. But because artillery vehicles alternately support maneuver units with directed fire and engage in counterbattery fire, these vehicles encounter different risks in each of the mission modes. Given a hit, the attrition, battle damage, and recovery diagram is valid for either mission, but an artillery vehicle is less likely to be hit in the counterbattery role, partly because counterbattery missions are shorter.

Table E.1

EXPECTED ACTIVE BATTLE REPAIR TIMES[a]

Vehicle	Organizational (Bn) (hours)	Direct Support (FAST) (hours)
M60A1	12	48 with p = 0.8 24 with p = 0.2
M113A1	6	48
M109A1	n.a.	12
M110A1	n.a.	24

[a]Repair times are expected values conditional on the availability of required skills. Manhours may exceed repair times hours depending on total repair requirements.

[1]Shishko and Paulson, *Relating Resources to the Readiness and Sustainability of Combined Arms Units*, The Rand Corporation, R-2769-MRAL, December 1981.

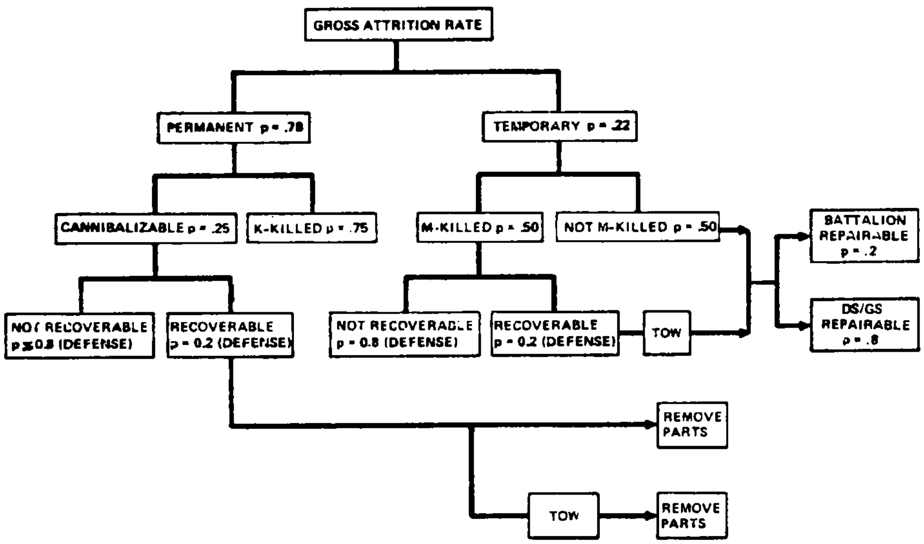

Fig. E.1—Attrition, battle damage, and recovery assumptions (M60A1 active defense)

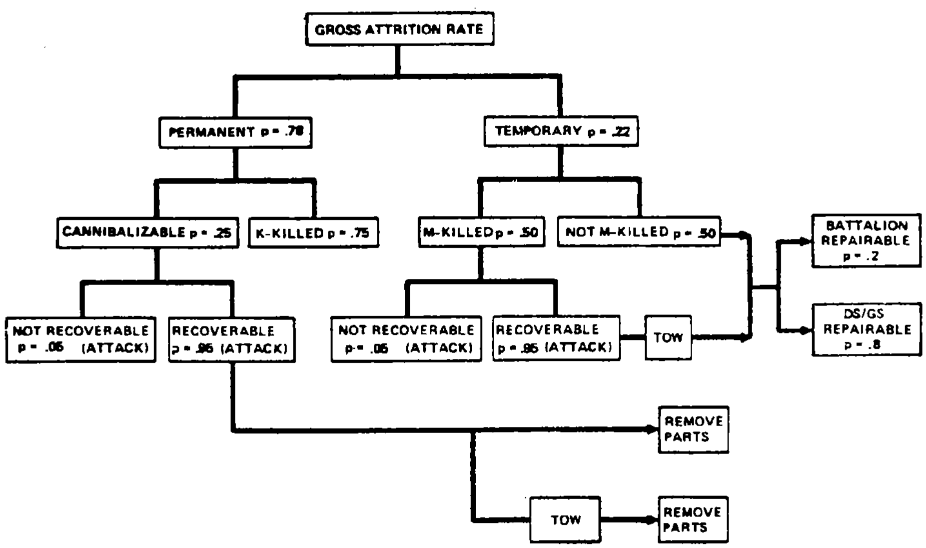

Fig. E.2—Attrition, battle damage, and recovery assumptions (M60A1 attack)

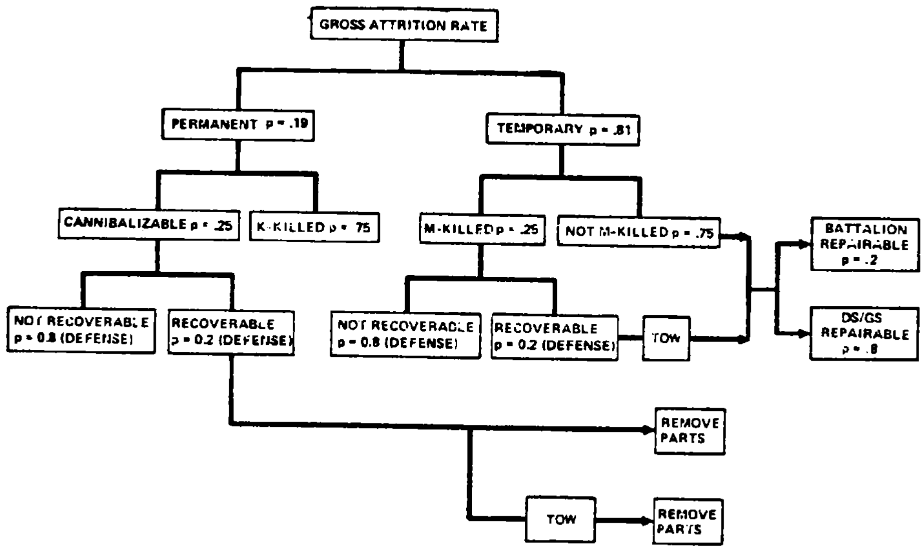

Fig. E.3—Attrition, battle damage, and recovery assumptions (M113A1 active defense)

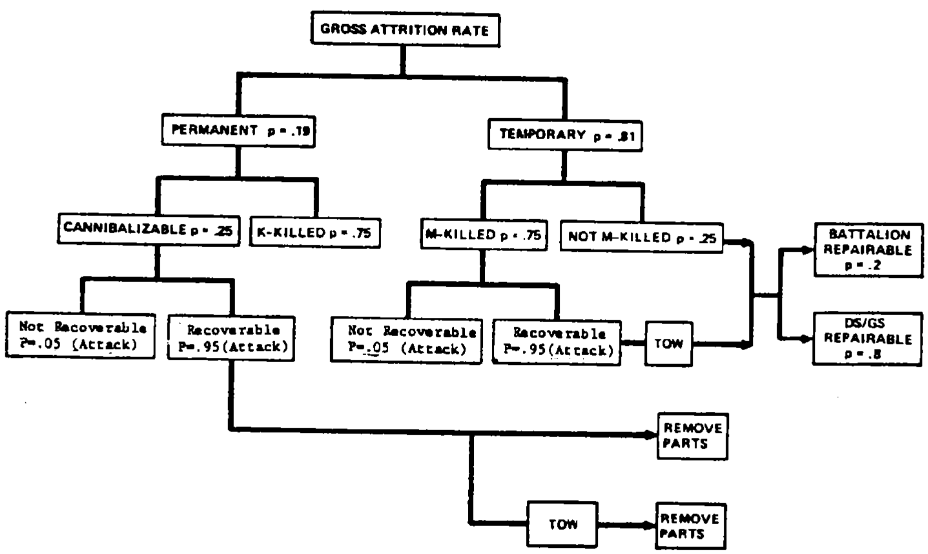

Fig. E.4—Attrition, battle damage, and recovery assumptions (M113A1 attack)

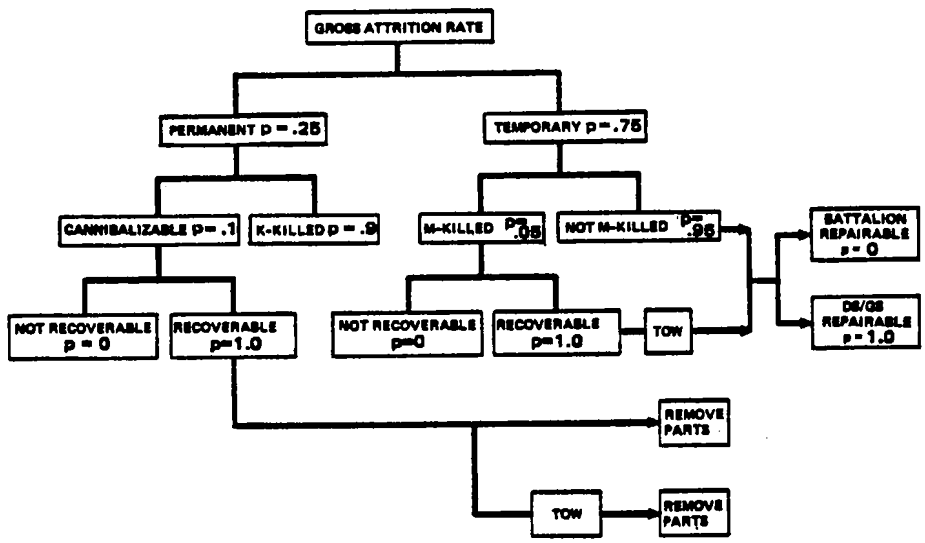

Fig. E.5—Attrition, battle damage, and recovery assumptions (M109A1 and M110 attack and active defense)

Appendix F

THE MATHEMATICS OF READINESS INDEXES

It is possible to define a readiness and sustainability index by using the output of a reference unit as a baseline. Let $q_{ij}^{k}(t;m)$ be the rate of output with mass m for the i^{th} SOC under the j^{th} oplan under the k^{th} unit at time t. Let T be the time horizon over which output is to be measured and τ the starting time for measuring output; then cumulative output with mass m for the i^{th} SOC under the j^{th} oplan by the k^{th} unit produced between τ and $\tau+T$ is given by

$$Q_{ij}^{k}(m,\, T,\, \tau) = \int_{\tau}^{\tau+T} q_{ij}^{k}(t;\, m)dt\ . \tag{F.1}$$

The rate of output of the k^{th} unit is a function of the resources consumed by the unit. Let $x_1^k(t), x_2^k(t), \ldots, x_n^k(t)$ be that set of resources—manpower, equipment, spares, POL, munitions, and so on—consumed by the k^{th} unit.[1] Then the left-hand side of Eq. (F.1) is more aptly written as

$$Q_{ij}^{k}(m,\, T,\, \tau) = Q_{ij}^{k}(x_1^k,\, x_2^k,\, \ldots,\, x_n^k;\, m,\, T,\, \tau)\ .$$

Another unit might have a different set of resources at its disposal and may therefore produce output at a different rate. Let $Q^{o}(m,\, T,\, \tau)(>0)$ be the cumulative output of a *reference* unit holding everything constant except the resource set; then we can define a simple readiness and sustainability index for the k^{th} unit as

$$R_{ij}^{k} = \frac{Q_{ij}^{k}(x_1^k,\, x_2^k,\, \ldots,\, x_n^k;\, m,\, T,\, \tau)}{Q_{ij}^{o}(x_1^o,\, x_2^o,\, \ldots,\, x_n^o;\, m,\, T,\, \tau)}\ . \tag{F.2}$$

[1]Some $x_i^k(t)$'s could represent services, as, for example, transportation service for ammunition. In that case $x_i^k = x_1^k(z_1^k,\, z_2^k,\, \ldots,\, z_m^k)$ where z_i^k's represent organic and non-organic cargo trucks, drivers, mechanics, MHE, spares, and POL dedicated to the movement of munitions to the unit.

In other words, a simple readiness and sustainability index for the k^{th} unit is its output *relative* to a reference unit. We standardize on the output of a reference unit because we believe commanders will have a greater appreciation for the readiness and sustainability of their unit when it is compared with a commonly accepted yardstick. The choice of the reference unit is arbitrary, but it makes sense to choose something to which Army commanders are attuned. For example, one might choose a unit with its full TO&E complement of manpower and equipment and unconstrained (at the SOC usage rate) ammunition, POL, and spares. Although no unit in the Army can expect these conditions in wartime, this set of resources should allow the unit to reach its maximum potential output.[2] In theory, the denominator of Eq. (F.2) could be any number, but regardless of what number is chosen for the denominator, the percentage change in the readiness and sustainability index is equal to the percentage change in output under that SOC.

As a readiness and sustainability index, Eq. (F.2) does not take into account two further considerations. First, for a particular SOC, the *utility of output* at a time t might grow faster or slower than the *output itself*. Second, within a particular oplan, output early in the battle might be worth more than output later—that is, a commander might be willing to exchange two units of output on D+15 for one unit on D+1. To allow for these possibilities, we can define a general readiness and sustainability index for the k^{th} unit as

$$R_{ij}^{k} = \frac{\int_{\tau}^{\tau+T} U_{ij}[q_{ij}^{k}(t, m), t]dt}{\int_{\tau}^{\tau+T} U_{ij}[q_{ij}^{o}(t, m), t]dt}, \tag{F.3}$$

where U_{ij} is a utility of output function under the i^{th} SOC and j^{th} oplan.

The readiness and sustainability index defined by Eq. (F.2) or Eq. (F.3) has a number of advantages over the C-ratings in AR220-1. First, it is a continuous function rather than a four-cell classification scheme. Second, the index is responsible to all *resources* that affect output. AR220-1 requires reports only on some inputs. Third, the

[2]Alternatively, the reference unit could be defined not with unconstrained spares, but with a PLL (Prescribed Load List) or ASL (Authorized Stockage List) defined by the MERPL (Mission Essential Repair Part List).

sustainability of resources is recognized by the proposed index. Thus two units with different resource sets that produce the same output would be rated identically, whereas under AR220-1 they might not be. As a result, the proposed index permits the management of resources to achieve various readiness and sustainability levels. Because AR220-1 does not recognize input substitutability, the resource manager has little discretion to alter the mix of inputs to maintain a readiness and sustainability level when relative scarcities change.

RAND/R-3156-MIL